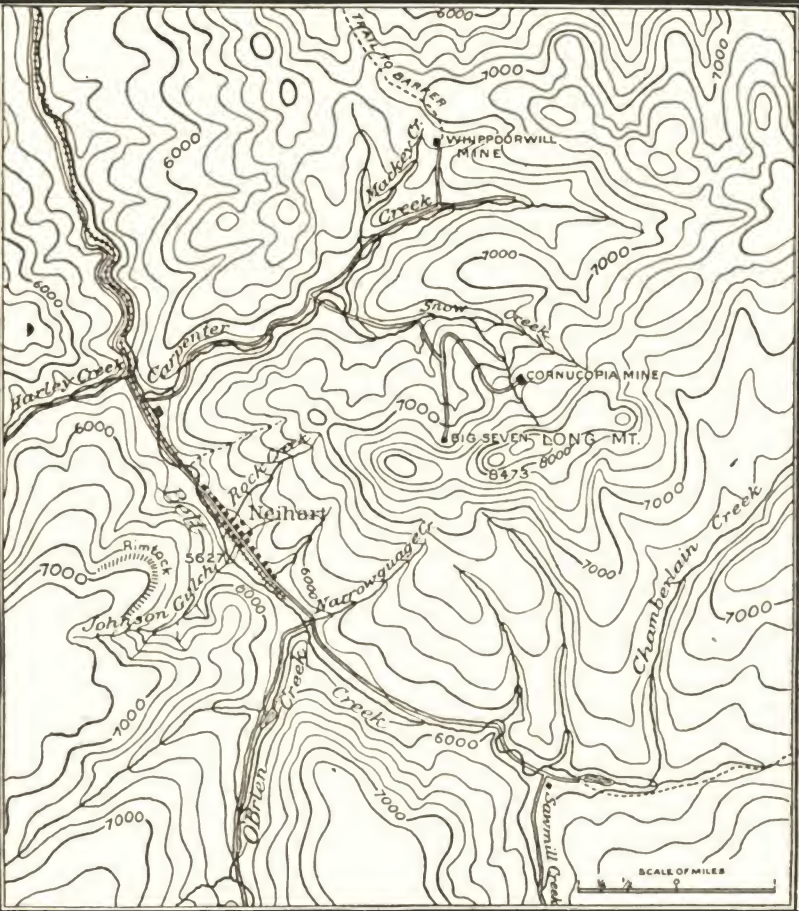

Geology of the Little Belt mountains, Montana

Walter Harvey Weed, Louis Valentine Pirsson

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DEPARTMENT OF THE INTERIOR—U. S. GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

GEOLOGY
OF THE
LITTLE BELT MOUNTAINS, MONTANA

WITH NOTES ON THE MINERAL DEPOSITS OF THE NEIHART BARKER, YOGO, AND OTHER DISTRICTS

BY

WALTER HARVEY WEED

ACCOMPANIED BY

A REPORT ON THE PETROGRAPHY OF THE IGNEOUS ROCKS OF THE DISTRICT

BY

L. V. PIRSSON

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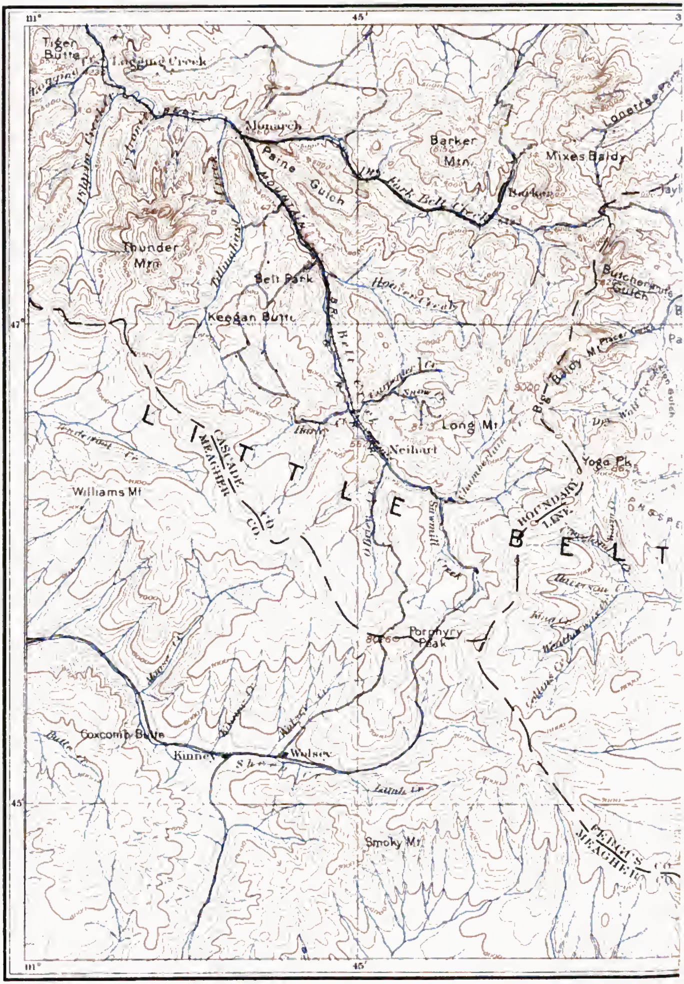

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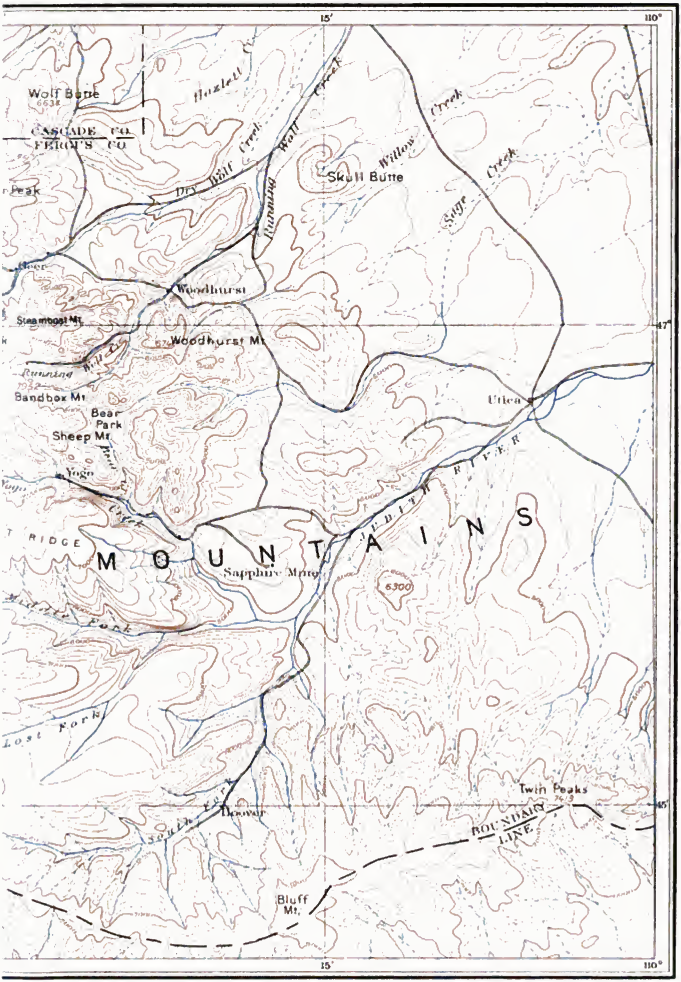

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GEOLOGY OF THE LITTLE BELT MOUNTAINS, MONTANA.

By W. H. Weed.

CHAPTER I.

INTRODUCTION.

The field work upon which the present report is based was done in September, 1893, and August, 1894, while the writer was engaged in an areal geologic survey of the region. During both these years he was accompanied by Prof. L. V. Pirsson, of the Sheffield Scientific School of Yale University, who shared with him the vicissitudes of camp life and visited nearly all the localities seen. The writer is under obligations to him for many keen observations in the field as well as for the careful petrographic study which he has made of the igneous rocks of the range (see accompanying paper).

Owing to the necessity of revising the topographic map, especially of the area about Neihart and Barker, the two mining settlements of the region, the preparation of this report was delayed until this revision was made, and in September, 1896, a part of the range was resurveyed by Mr. R. H. Chapman, but the heavy autumnal showers prevented further geologic field work in that year. In 1897 three weeks were spent at Neihart revising the geologic boundaries of the new map and visiting the ore deposits of the district. The author was in that year assisted by Mr. L. S. Griswold, formerly of the geologic staff of Harvard University, now of Helena, Montana. To him was intrusted the delineation of the contact boundaries of the igneous masses about Barker and a study of the ore deposits.

All of the range does not appear on the folios issued by the Survey, though both the Little Belt Mountain folio, named from the range, and the Fort Benton folio include parts of the chain.

It must be remembered that the study of the region was incidental to this areal mapping and that it was not a detailed investigation. For this reason, and because of the small scale of the map, this report must be regarded as a general description only.

GEOGRAPHIC POSITION.

The Little Belt Mountains are situated in the central part of the State of Montana, as shown on the index map (fig. 36). They form part of the Rocky Mountain region, being one of the eastern of the bordering or front ranges, which project from the general mountain area into the open country of the Great Plains. They lie to the south of the plains of the Missouri River and midway between that stream and the Yellowstone. Their drainage is, however, all tributary to the Missouri. The range has a general northwest-southeast trend. It is clearly defined between the plains country and the broad intermontane valley of Smith River, but its western extension is indefinite, though currently accepted as ending where Smith River has cut its valley northward through a relatively lower though somewhat mountainous country. The mountains were seen by Lewis and Clarke in their historic trip up the Missouri River in 1804–1805. They undoubtedly derive their name indirectly from Belt (or the Belted) Butte, a conspicuous eminence rising above the open plains country north of the mountains. Belt River, named from the butte, has its source in the range, and no doubt suggested the name of the latter, while the relatively low elevation and plateau character of the mountains, as contrasted with the range south of it, suggested the adjective Little, in contradistinction to Big Belt.

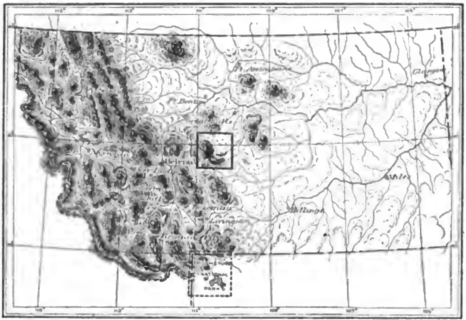

FIG. 36.—Index map, showing location of range.

SETTLEMENTS.

The gold discoveries which brought a host of energetic prospectors into the State in the sixties resulted in a general searching of the mountain region of Montana for mineral deposits. It was not, however, until 1876 that the discovery of the silver-lead ores of Barker directed especial attention to this tract. Neihart is now the principal town, with a population varying from 500 to 2,000, according to the activity in the mines. Barker, though nearly deserted for many years, has now a few hundred inhabitants. Monarch, a distributing point for the Kibbey Basin, is the only other town within the mountains, though post-offices are maintained at a few points for the benefit of the scattered settlers of the region. A branch line of the Great Northern Railway extends from Great Falls into the heart of the range, lines running to both Neihart and Barker. There are very few wagon roads, and the greater part of the range is accessible only on horseback, though the road to White Sulphur Springs runs across its center.

The climate is rigorous, as would be expected from the elevation. Outside of the few small bottom-land areas along the creeks, and the meadows of Belt Park, no crop except hay can be raised. The arable land is limited and the region has no agricultural possibilities.

The general elevation being over 6,000 feet, the snowfall is heavy, and the roads across the range are blocked by the deep drifts as late as June. June and October are commonly stormy months, but the intervening summer period is characterized by an almost ideal climate.

PREVIOUS EXPLORATION.

In 1883 Prof. W. M. Davis crossed the range, visiting Neihart, in an economic exploration conducted for the Northern Transcontinental Survey of the Northern Pacific Railroad Company. He published a brief account of his observations in the Report of the Tenth Census on Mine Industries.[1] He gives the main facts of geologic structure and stratigraphic sequence, and noted especially the fine geologic sections in the northern part of the range. He was accompanied and assisted in this work by Mr. Waldemar Lindgren, who made a special study of the igneous rocks, described their occurrence, and gave a description of the principal rocks. His work will be alluded to later. In 1884 Prof. J. S. Newberry visited Neihart and looked over the ore deposits there, and in the same year he published a short account of his observations on the geology of the range.[2]

TOPOGRAPHY.

The Little Belt Mountains are commonly spoken of as a range, but are more correctly designated as an elevated and eroded plateau region, as is plainly shown by the topographic map (Pl. XXXVI). Individual peaks along the northeastern flank rise above the general level, and give the serrated crest line seen from the open plains. Compared with the compact, well-defined mountain ranges common in the Cordilleras, the Little Belt tract is relatively low, wide, and composed of many spurs radiating from a central point. The mountains constitute, however, a tract sharply delimited from the adjacent plains country on the northeast and southeast, and separated by the broad and flat Smith River Valley from the Big Belt Range. Westward the deep canyon of Smith

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[1] Relations of the coal of Montana to the older rocks; with appendixes on fossils by R. P. Whitfield and on eruptive rocks by W. Lindgren: Report of Tenth Census, Vol. XV, pp. 696–737, Washington, 1886.

[2] Annals New York Acad. Sci., Vol. III, No. 8, 1884.

River outlines the border of the mountains, the region beyond being of gentler relief, in strong contrast to the western slopes of the Little Belt. The region thus delimited is 60 miles across from east to west, 40 miles wide on its western border, and narrows eastward to a sharp point terminating at Judith Gap. The letter V represents the plan of the mountains, the angle pointing east.

The water parting of the mountains is the approximate axis of the uplift, though not the highest part of the mountains. It runs northwest and southeast, and this is commonly spoken of as the trend of the range.

Throughout the greater part of the region the mountains are plateau-like. There are no narrow crest lines marked by arêtes or sharp peaks, but broad, flat tops prevail. The average elevation is 7,600 feet, though in the central tract from which the spurs radiate the summit level is 8,000 feet. While this plateau character prevails over the greater part of the tract, the higher summits found along the northeast border rise above this general level, are different in form, and more or less isolated. The highest summit of the mountains, called Big Baldy, reaches an altitude of 9,000 feet. The other peaks are much less in height. These mountain masses show rounded or dome-shaped summits, which rise above and are distinct from the rest of the range. These individual mountain masses owe their prominence to geologic structure, as will be shown later in this report. The Little Belt Mountains are bounded by soft and easily eroded rocks, and owe their prominence as well as their uplifted position to this fact. Within the mountain tract rock characters and geologic structure determine topographic form. So intimate is this relation that it is difficult to discuss one without discussing the other.

There are no big and broad valleys within the mountains. The streams flow in deeply trenched courses, open and wide in the softer shaly rocks, narrow canyons in the harder limestone strata. The region is sufficiently rugged to be characterized as mountainous, though only alpine about the highest peaks. Summit plateaus are bordered by high escarpments, and along the streams the towering limestone cliffs, walling in deep gorges, present difficulties to travel and lend picturesqueness to the scenery.

Secondary plateaus are common in the central area, where the beds are horizontal or gently inclined. Resistant rocks determine broad levels separated by deep gorges, and where such levels are emphasized by differences in vegetation, as is the case in Belt Park and the other quartzite parks near Neihart, the contrast with the wooded slopes above and below is very marked. Smaller benches, due to igneous sheets, are also common. The smaller parks of the mountains owe their existence to soft rocks. Bear Park and several other park valleys are formed of synclinal folds of Carboniferous shale.

Along the mountain flanks the streams cut across the upturned beds in narrow gulches. Here the abrupt transition from soft to harder rocks is strikingly shown in the resulting scenery. The streams pass through narrow clefts in the massive limestones—gateways from the open, arid plains to the verdure-clad mountain valleys. Along the larger streams such gorges are wider, though generally impassable, and the limestones present a bewildering array of pinnacles and towers, castle-like masses, natural archways, and ribboned walls.

DRAINAGE.

The region is well watered, the rainfall and snowfall being relatively abundant. The range is a center from which streams radiate in all directions, but the Judith, Belt, and Smith rivers are the trunk streams, draining the east, north, and west slopes, respectively. So far as it has been studied, the drainage is consequent. Smith River is, however, a reversed stream, and a northward tilting in recent geologic time has accelerated northward-flowing streams and retarded southward drainage ways, and its effects are seen in one or two beheaded and reversed streams.

The character of the streams is dependent upon the nature and structure of the rocks, and accordingly the streams are perennial, intermittent, and interrupted.[1] The former occur only in impervious rocks, shales or the igneous rocks. The intermittent streams, flowing only in wet weather, or the time of melting snows, are common where the catchment area is small, but are especially characteristic of limestone areas, where the waters sink and are lost in the rocks. Where the structure brings an underlying impervious stratum or an igneous rock to the surface, such waters often reappear as springs. About the mountain flanks the dry drainage ways which cross the surrounding plain often have springs a few miles from the mountains. The "interrupted" streams have flowing water only where their channel is cut in impervious rocks. In the limestone areas, even a large and rapidly flowing stream will sink beneath the surface and disappear, leaving the stream channel bare and dry until, at some lower level, the water comes to the surface and forms a flowing stream for a short distance, and then disappears again. Dry Fork of Belt Creek, and Belt Creek below Monarch, and the forks of the Judith exhibit this character during the summer months. There are no waterfalls in the mountains. The streams have, however, a steep gradient, and water power is readily available. Belt Creek has a fall of 1,677 feet in 27 miles, from Neihart to the point where it leaves the mountains at Riceville. The grade is 82 feet per mile between Neihart and Monarch, 47 feet per mile between Monarch and Logging Creek, and 40 feet per mile through Sluicebox Canyon.

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[1] Terms proposed by R. T. Hill, Geologic Atlas U. S., folio 42, Nueces, Texas; Washington, 1898.

VEGETATION.

The mountains are very generally forest clad, their dark slopes being in somber contrast to the surrounding arid plains. The timber is, however, mostly small. Yellow or lodgepole pine (*Pinus murrayana*) is the prevailing species. In some tracts it forms forests whose trees are 10 to 14 inches in diameter; but more commonly it is smaller, and burned-over tracts have a dense thicket of pole pine. The usual character of the forest growth of this species of pine is shown on Pl. XXXVII, *B*. Spruce and fir are also found along wet stream bottoms and on moist and cold northern exposures. The white pine (*P. flexilis*) is also found on the plateau summits, and south of Neihart has been extensively cut for lumber.

The character of the timber growth varies with the exposure. On southward-facing slopes the growth is sparse and open, with grassy interspaces. On northerly exposures thick and dark forests prevail. The plateau summits are beautiful in their alternation of glade and grove. The grouping of pine and spruce is ideal in form, and the opens are bright with innumerable flowers. The growth also varies somewhat with the character of the rock, or rather with the physical nature of the soil formed. The barren Belt shales produce but little soil and support scanty vegetation. The sandstones and quartzites and the fine débris of igneous rocks are generally densely wooded. The Cambrian shales, on the contrary, usually underlie an open, park country.

STRUCTURE.

The general structure of the Little Belt Range is that of a low flat-topped arch, which is 20 miles wide on the west and narrows to a point on the east. On the summit of the arch the rocks are gently inclined or horizontal. On the flanks or shoulders of the arch the rocks dip steeply away from the uplift. This is shown in the sections, drawn to natural scale, across the range, contained in folios Nos. 55 and 56, of the Geologic Atlas of the United States.

This simplicity in structure is modified by a great fissure extending from Yogo Peak northeastward for 13 miles. This fracture, filled by igneous rocks forming a stock,[1] was the center from which numerous sheets and dikes were sent out as intrusions in the softer shaly strata. An even greater modification of the general arch of the range is seen along its northern flanks, where great bodies of igneous rocks are found intruded between the crystalline schists and gneisses and the overlying sedimentary rocks. These intrusions are laccolithic in character and arch up the beds above them, thus locally elevating the latter far above the general summit of the range fold. These local arches are not confined to the mountain areas, but also occur on the outlying low plains country north of the range. As a result of the powerful

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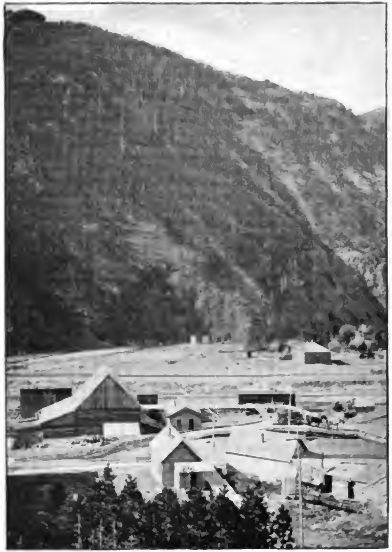
[1] An irregular intrusive body of igneous rock of unknown depth, breaking across and up through earlier rocks; often a trunk mass for radial dikes and sheets.



A ARCHEAN SLOPES AT NEIHART MONTANA

Showing smooth steep slopes formed by the more schistose rocks

B FOREST GROWTH ON PORPHYRY BENCHES, STAGE ROAD UP SAWMILL CREEK NEAR NEIHART, MONTANA movements by which the range itself was uplifted and arched, and of those lesser movements by which the stratified rocks were subjected to further uplift and folding, there are many dislocations and minor foldings. As shown on the map, there are no great faults throughout this area, the dislocations being small and purely local in character.

Ore deposits occur in many parts of the range, but up to the present time those of the Neihart and Barker districts are the only ones that have yielded productive mines. Their association with the igneous rocks appears to be very close, if not directly genetic. The mineral deposition is found to be relatively recent, being later than the youngest eruptive rocks.

Since the uplift of the range, with the accompanying intrusion of igneous rocks, the region thus raised above the general level has been extensively denuded. This period of erosion has bared the larger laccoliths and worn down the general level to the plateau-like region now seen. In this process the relative hardness of the different rocks, or their resistance to erosion, has resulted in a differential degradation, in which the harder igneous rocks are left in relief, and now form the higher summits by virtue of their physical character as well as their uplifted position.

This region, unlike that of Castle Mountain to the south, has not held local ice sheets, nor has it been covered by the general glaciation from the north. A careful search was made for traces of glaciation, but none were found whose origin was certain, although it was supposed by Newberry that the range was once ice clad. The igneous rocks of the mountain are peculiar and easily recognized, but do not occur in glacial drift farther north.

Stream erosion has been active, and the range presents evidence of stream adjustment and vigorous cutting as a result of later tilting of the region to the northward.

CHAPTER II.

THE ROCK FORMATIONS.

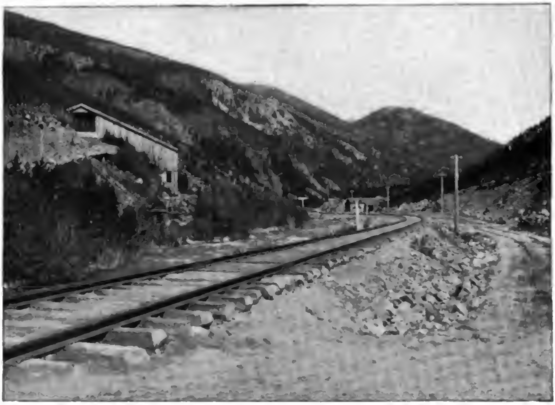
The rocks of the Little Belt Mountains are of many kinds and of diverse origin. The nucleus or core of the range, which is exposed about Neihart and on lower Sheep Creek, consists of gneisses and schists, a group which has at many localities been designated as a Basement Complex. Sedimentary rocks rest upon this central core, and cover the greater part of the range. They cover a wide range in lithologic character, and include formations of all the geologic ages. The sedimentary strata are intruded by igneous rocks, which break up through them in great stocks or in dikes, or are intruded between the beds as sheets or laccoliths. These igneous rocks also present a considerable variety in texture and composition. The areal distribution of the different rocks is shown on the geologic map, Pl. XLI.

METAMORPHIC ROCKS—GNEISSES AND SCHISTS.

The crystalline schists which occur in the Little Belt Range have the characters common to the Archean or Basement Complex elsewhere. They are the oldest rocks and form the nucleal core of the range. The rocks are well banded, the layers preserving a uniform direction for many miles. Upon the truncated edges of these bands the stratified rocks rest in an unconformity that is as marked as is the difference in texture between the metamorphic and the unaltered or but slightly altered strata. North of Neihart, Cambrian rocks rest directly upon the gneisses. South of Neihart a thickness of 4,000 to 5,000 feet of Algonkian rocks intervenes, separated from the Cambrian by an unconformity.

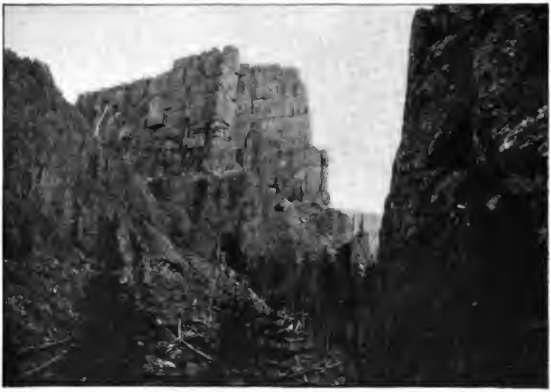
In no part of the series examined do the rocks possess the recognizable characters of altered sediments, and if subdivisions of the Archean are made it must be on purely lithologic grounds. A part of the series is demonstrably eruptive, and the rocks are cut by later and but partially metamorphosed igneous rocks. The banding and foliation that are so striking in general view do not afford a satisfactory basis for a subdivision of the series, since the rocks rapidly change in character. The general character of the Archean slopes is shown in Pl. XXXVII, *A*, and Pl. XXXVIII, *A*, made from photographs of the slopes near Neihart.

The crystalline schists present considerable variety in color, texture, mineral composition, and in those physical characteristics which show



A. VALLEY OF BELT CREEK, 3 MILES BELOW NEIHART.

Cut in gneiss Old concentrator on left



B. CANYON OF BELT CREEK 3 MILES SOUTHEAST OF NEIHART.

Cut in Neihart quartzite.

in weathering, and cause the rock to form bold outcrops or soil-covered slopes, massive talus débris blocks or slopes of fine, gravelly débris. These characters affect to a very marked degree the nature of the vein fissures, and also the character of the ore of the veins. Nevertheless, it was not found possible to map these distinctions, partly on account of the very small scale of the topographic map and partly because of the nature of the rocks themselves. Though presenting apparently so wide a variety of rock types, all the rocks can be classed as crystalline schists, and are either gneisses or schists of various kinds. Collectively they form a remarkably well-defined series of rocks, and they are mapped as a unit.

The "crystalline schists" are rocks distinctly crystalline in texture, showing a streaked or foliated structure, due to the aggregation of different constituents into parallel layers, which are generally distinct in texture and composition from adjacent layers. These layers or folia are not persistent, but are thin lenticular bands, which thicken and thin out rapidly, the ends of different folia interlocking. The rocks split along these folia more or less readily (schistosity). This arrangement is seen on a large scale as banding; in a hand specimen it is generally recognizable, and always in microscopic sections.

While part of the Neihart rocks are true schists, none of them are the wrinkled, puckered schists common in so many Archean areas. Most of the rocks are gneisses, using the word to denote or designate any crystalline rock possessing a gneissic structure, and not confining it to a quartz-mica-feldspar rock simply. They are foliated rocks, not sufficiently fissile to be called a schist. In none of the Neihart gneisses or schists has any evidence of a sedimentary origin been observed. On the other hand, many of them are still recognizable as metamorphosed igneous rocks, mostly porphyries, which can be distinguished without difficulty from the later and unchanged intrusions of porphyry. Where the original character of the rock is not determinable it is distinguished by the name of its predominant or characteristic mineral.

ALGONKIAN ROCKS.

BELT TERRANE.

Throughout the southern portions of the mountain tract there is a great thickness of generally barren slaty rocks underlying the Cambrian formations. This series, which consists of several distinct but allied formations, collectively known as the Belt terrane, is shown upon the geologic map under the names of Neihart quartzite and Belt shale. This formation is wanting in the northern part of the range, where the fossiliferous Middle Cambrian rocks rest directly upon the crystalline schists. Throughout the entire southern part of the mountain area it is exposed where the denudation has cut deeply enough into the uplift, and these rocks here form the surface over extensive districts. Volcano Valley, between the Little Belt Range and Castle

Mountain, is eroded in an anticline of these rocks, and the Big Belt Range is a long anticlinal uplift formed of them.

The Belt terrane consists of seven distinct formations, only five of which are found in the Little Belt region. The formation was first recognized by Davis in 1882,[1] and described as probably Lower Cambrian. It was also noted by Newberry in a trip across the Belt Mountains in 1884. The southern extension was mapped and described in folios 1 and 24, and in bulletins 110 and 139, of the United States Geological Survey. The best exposures of the Little Belt and Big Belt ranges were carefully examined at different times in each successive field season for traces of fossil remains, and in 1895 a reconnaissance of the region was made by Mr. Charles D. Walcott, the director of the Survey, accompanied by the writer, in search of fossil remains. Despite a prolonged search at that time, it was not until the summer of 1898, when a second visit to the region was made by Mr. Walcott, that fossil remains were found. The character of these remains does not contradict the distinct stratigraphic evidence of a great unconformity and of an interval of erosion between these and the overlying beds, and the terrane is assigned to the Algonkian period.

Topographic aspect of Belt areas.—Between the areas covered by the rocks of the Belt terrane and those of later sedimentary strata there is a marked contrast in topography, and usually in vegetation also. This is due to the prevailing shaly character of the Belt rocks, the thin and barren soil formed by them, and their usually rapid degradation. In general, the country covered by the Belt terrane is a hilly one, with smooth and rounded slopes, deeply trenched by flowing streams. The larger valleys are bordered by bluffs of these rocks.

The formation as a whole is well indurated and somewhat metamorphosed. In this respect it presents a strong contract to the overlying Cambrian strata, whose unaltered shales and limestones bear no resemblance to the slaty rocks of the Belt. There is no true slaty cleavage, however, but there are bedding laminations, and the rocks are more properly called phyllites or argillites, though slate appears to be a more popular or commonly used descriptive name.

No general review of the literature of the terrane will be given here. Van Hise has presented an admirable summary of it,[2] as did also Peale[3] in 1893. Neither Peale nor Davis recognized definite subdivisions of the terrane, though both allude to the variety of rocks composing it. The first attempt to subdivide the group was made by the writer in the Castle Mountain region.[4] When the vicinity of Neihart was studied the base of the formation was named the Neihart quartzite, and the different subdivisions overlying this were recognized, though for purposes of areal mapping they were grouped as Belt shale. In a paper by Mr. Walcott these formations were for the first time given individual names and defined as separate formations.[1] The subdivision is, however, based entirely upon lithological grounds, though the terrane presents an ideal example of a cycle of deposition,[2] and the subdivisions grade into one another. The formations composing the terrane, corresponding in part to those made by the writer in 1896,[3] have been named by Mr. Walcott as follows, the beds being given in descending order:

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[1] Tenth Census, Vol. XV, p. 738.

[2] Bull. U. S. Geol. Survey No. 86, pp. 286, 504. Principles of pre-Cambrian geology: Sixteenth Ann. Rept. U. S. Geol. Survey, Part I, p. 818.

[3] Bull. U. S. Geol. Survey No. 110, pp. 16-20.

[4] Bull. U. S. Geol. Survey No. 139, p. 32.

7. Marsh Creek shale.
6. Helena limestone.
5. Spokane shale.
4. Greyson shale.
3. Newland limestone.
2. Chamberlain shale.
1. Neihart quartzite.

The two upper formations are not found in the Little Belt Range, but occur on the flanks of the Big Belt Range in a continuation of the terrace to the west and north.

Neihart quartzite.—The oldest recognizable sedimentary rocks of the Little Belt Mountains are the quartzite beds found in the vicinity of Neihart. On Neihart and Long Baldy mountains the quartzite is seen resting directly upon the crystalline schists, and the picturesque canyon about Neihart is cut in it. The rocks are in part true quartzites, grading into well-indurated sandstones. They sometimes show well-developed bedding, though they are often quite massive in general view. In color they vary from creamy white to gray or pink. Pebbles are occasionally found, masses of which sometimes form thin lenses, but their occurrence is local and no well-defined conglomerate beds occur. They consist for the most part of milky white, or pink, rarely gray, quartz. Red and white gneiss is occasionally seen, but no pebbles of the Pinto diorite or other igneous rocks intrusive in the crystalline schists were found.

The lower 350 feet of the quartzite forms a very compact body, uniform in character, which makes the escarpments so conspicuous from Neihart. The rock shows a prismatic structure, especially conspicuous in Neihart Canyon, and shown on Pl. XXXVIII, *B*. About 300 feet above the base the character of the formation changes. The pink and white pure quartzites are replaced by more thinly bedded rocks, no longer of pure arenaceous material, but containing an admixture of greenish mica, which higher in the group forms the layers of mica shales interbedded with the quartzite. The higher strata are still more impure and the quartzite beds are but 6 to 12 inches thick, blackened by carbonaceous material that now forms a prominent feature of the intervening shales, becoming increasingly abundant until the latter rocks are true black shales in which the green mica no longer shows. At the same time the quartzite beds decrease in thickness and purity, while the interbedded shale increases in thickness and purity, so that an arbitrary line must be drawn separating the two formations.

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[1] Fossiliferous pre-Cambrian terranes: Bull. Geol. Soc. America, Vol. X, pp. 199–244.

[2] Newberry, cycles of deposition of American sedimentary rocks: Proc. Am. Assoc. Adv. Sci. August, 1873, p. 185.

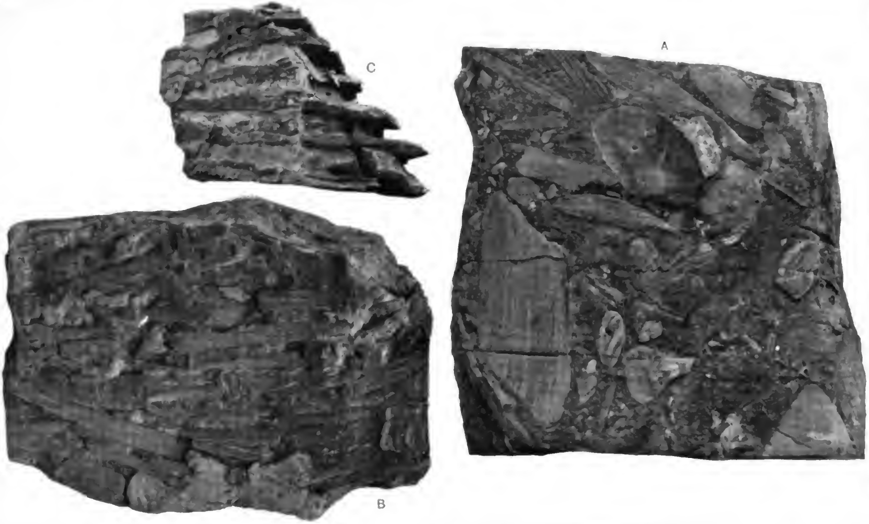
[3] Bull. U. S. Geol. Survey No. 139, p. 32.

Chamberlain shales.—These consist of a series of dark-gray, almost black, shales, frequently arenaceous, showing occasional ripple marks. The rocks are essentially slaty in fracture, but the beds are jointed and form cliffs along the stream courses. The formation is characterized by these black shales, which form its middle part. At the base the admixture of arenaceous and micaceous material indicates transition into the underlying quartzite, while in the upper part of the formation calcareous beds appear alternating with the black shale, the latter becoming less and less prominent and the calcareous shale becoming true limestone. There is thus a very gradual transition into the Newland limestone, and no sharp dividing line can be drawn. The estimated thickness of the Chamberlain is 2,000 feet, and it is typically developed along Chamberlain and Sawmill creeks south of Neihart. The thickness on Sawmill Creek is estimated to be 2,078 feet.

Newland limestone.—The base of the formation consists of beds of limestone but 12 to 30 inches thick, at first separated by 20 to 50 inches in thickness of shale. Higher up in the series the limestone beds become more frequent and thicker and the shale layers thinner, until in a few hundred feet the limestone largely predominates. These lower limestones are somewhat fissile and shaly. In the center of the formation they are massive, very dense and compact, dark-blue in color, and show crystalline streaks and markings (calcite) and carbonaceous stainings. The rocks weather with a light-yellow or buff color, on which these crystalline markings are prominent, and are generally cracked by fine joints, frequently filled with calcite, which causes the rock to break into small cubical masses on weathering. In the middle of the formation there is little or no shale. The limestone occurs in beds 3 to 6 feet thick, sometimes thicker, and is jointed, so that the exposures present a masonry-like effect when seen in cliffs. The formation is typically exposed in the bluffs on the north side of Newland Creek, from which it takes its name. The thickness along Sawmill Creek is estimated at 567 feet; on Newland Creek it is much greater.

Greyson shale.—This formation consists of dark-gray or black, fine and coarse grained siliceous shales. The lower part of the formation consists of pearly gray shales containing mica (sericite), which gives the rock a glistening, satiny sheen. These pass upward into more siliceous beds containing beds of intercalated sandstone a foot thick. The formation is exposed in the bluffs at Sawmill and Belt creeks, and covers large areas in the southern part of the mountains. The thickness on Sawmill Creek is 955 feet.

Spokane shale.—The highest beds of the terrane seen in the Belt Mountains are the red shales given this name. The rocks vary from



A. CONGLOMERATE OF LIMESTONE PEBBLES FROM THE PARK SHALE (CAMBRIAN).
B. INTRAFORMATIONAL CONGLOMERATE OF LIMESTONE-LENSES, PILGRIM LIMESTONE (CAMBRIAN).
C. CHERT LAYERS IN CAMBRIAN LIMESTONE, SHOWING RELIEF WEATHERING

brick-red to pink in color, and are therefore usually easily recognizable, though seldom forming good exposures. South of Neihart they are seen in Sawmill Creek, just below where the road makes a sharp bend to ascend to the park. The formation has not been recognized on Chamberlain, Belt, or O'Brien creeks. The unconformity between these shales and the overlying Flathead (Cambrian) quartzite is seen on Sawmill Creek. Southward these red shales are very prominent on lower Newland Creek, where maroon shale is overlain by light-red and these by white shales.

General section.—The following section was measured along Belt and Sawmill creeks south of Neihart:

Section exposed on Belt Creek south of Neihart, Montana.

	Feet.	
Flathead sandstone:		
Cambrian sandstone; dark red, containing white pebbles, with quite ferruginous matrix. But 40 feet exposed, the bed occurring in the creek channel one-fourth mile below the forks of the stream	100	
Plane of unconformity.		
Spokane shale:		
Red shales	200	
Red shales, laminated, brittle, and quite hard	10	
Greyson shale:		210
Shales; generally gray, rarely exposed, and forming densely wooded slopes	700	
Gray sericitic shale, locally disturbed by a horizontal sheet of minette	170	
Shales; exposed in wall on west side of canyon. Thinly bedded slates carrying limestone	60	
No exposure	25	
Newland limestone:		955
Massive, block-jointed limestones, blue on fresh fracture and weathering earthy brown. Dip 20° S	15	
Calcareous shales or slates, not exposed	200	
Limestones, with massive outcrop, blue on fresh fracture, weathering on surface to an earthy buff color	60	
Slates. (Prospect hole shows a minette intrusion)	125	
Limestone; fissile and slaty	18	
Massively bedded slate	15	
Impure limestone	5	
Black or gray slate with glistening surface. Dip 30°	15	
Trachyte intrusion. Rock at contact badly twisted, probably not a sheet.		
Limestone and slate, not exposed	30	
Minette sheet.	6	
Limestones and shale	20	
Shales; slaty, in part indurated. Dip 20° S.; strike S. 60° E	15	
Slaty shale; gray in color, well indurated	30	
Limestone; in 3-foot beds of dark-gray color with crystalline markings	8	
Chamberlain shales:		562
Gray shale, seen in débris only, no ledges being seen	1,095	
Black shale; exposure being one-fourth mile below a western branch of the creek	363	

Chamberlain shales—Continued.	Feet.	
Massively bedded, black shale. Dip 20° upstream	40	
No exposure	190	
Black shale	40	
Black crumbly shale. Dip 14°	54	
Black shales	229	
Thinly bedded and fissile quartzite	5	
Black shale, somewhat slaty, carrying beds of green quartzite	40	
Shale, not exposed	22	
		2,078
Neihart quartzite:		
Quartzite	2	
Micaceous shale with fucoidal markings, resembling Cambrian	1	
Quartzite; greenish in color, occurring in beds 6 to 18 inches thick, with intervening black, carbonaceous shale	7	
No exposure	95	
Shales; micaceous, dark colored, generally green, and carrying thinly bedded quartzites, so that the entire series might be classed as quartzite	15	
No exposure	170	
Green, micaceous shale and micaceous quartzite occurring in beds 4 to 12 inches thick, in alternate layers	8	
Micaceous shales, resting upon basal quartzites	104	
Quartzite series, forming base of formation	300	
		702
Total		4,607

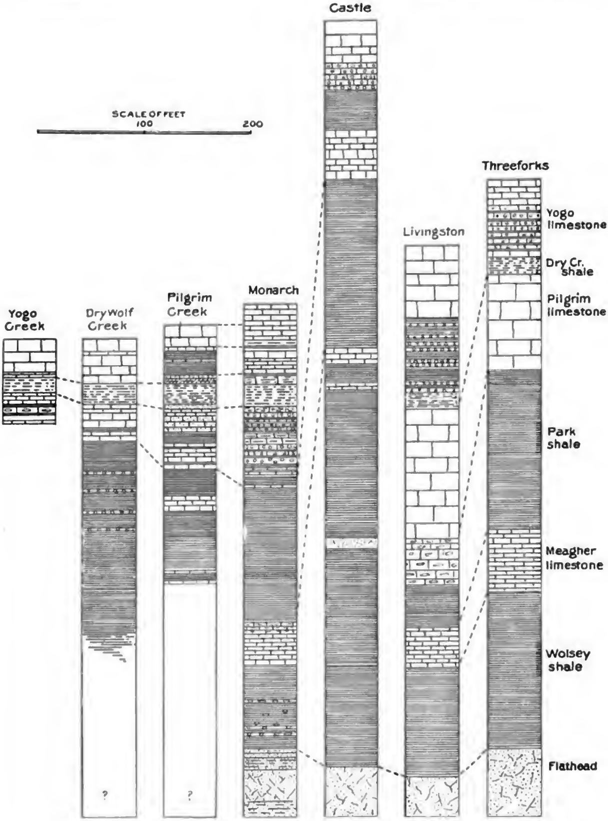
Unconformity.
Metamorphic gneiss.

CAMBRIAN ROCKS.

Distribution and subdivisions.—The strata of this age are an important element in the geology of the region. They cover a wide extent of country and determine its topographic character, and to a certain extent the nature of the vegetation. The formations composing it have influenced the character of the mountain folding and determined the site and nature of the numerous and great intrusions of igneous rock which compose the most prominent mountain masses, and upon whose existence some, at least, of the ore deposits are dependent.

The fossils show that the Cambrian rocks of this range are of Middle Cambrian age. The area covered by them is indicated by a single color on the geologic map (Pl. XLI), and the rocks are grouped under the name of the Barker formation. The beds thus grouped show well-defined lithological subdivisions, and in the ranges to the south and in the Yellowstone Park have been subdivided into two formations. This subdivision is, however, unsatisfactory, and since a careful study of the fossils found by Mr. Walcott shows that the forms are all Middle Cambrian species, the writer has divided the rocks of this age into the following formations:

7. Yogo limestone.
6. Dry Creek shale.
5. Pilgrim limestone.
4. Park shale.
3. Meagher limestone.
2. Wolsey shale.
1. Flathead sandstone.



COMPARATIVE COLUMNAR SECTIONS OF MIDDLE CAMBRIAN FORMATIONS IN CENTRAL MONTANA

Locality name at top of column.

The character and thickness of each of these formations are represented graphically on Pl. XL, where columnar sections measured at various localities in the range are shown.

Flathead sandstone.—The base of the Cambrian is formed by a quartzite, which in the Little Belt Mountains is somewhat fissile, impure, and shaly in the middle, so that the formation consists of three members. The lowest bed is a granular but generally well-indurated sandstone, of a white, pink, or dark-red color, often cross bedded, and occurring in strata 3 to 10 feet thick. The base is often a conglomerate. The following section, made in the bluff of Belt Creek 8 miles south of Monarch, shows the composition of the formation.

Section on Belt Creek 8 miles south of Monarch, Montana.

	Feet.
Wolsey shale:	
Ferruginous sandstone carrying fossil remains	10
Flathead sandstone:	
Quartzite; white	1½
Sandstone; rust colored and rotten	5
Sandstone; dirty white to buff; flaggy	15
Sandstone; fissile, impure, purple, and rust colored	30
Sandstone; massive	1
Quartzite; flaggy	6
Quartzite; vitreous, hard, massive, knotty, neither well bedded nor fissile	60
Augite-syenite sheet; 70 feet thick.	
Sandstones; dark red and ferruginous	25–50

Intrusions are frequently found elsewhere in the horizon here occupied by the syenite. The upper sandstone, a white granular rock, weathering with a pitted, pockety surface, covers Belt Park, and is exposed in the little gullies that indent its surface. On Sawmill Creek and along the O'Brien Creek road the basal bed was not measured, as no good exposures were observed, but its thickness was estimated to be 50 feet. A sheet of porphyry 50 to 60 feet thick is intruded between this lower bed and the higher quartzite. The latter differs in appearance. The rock is not so distinctly bedded, and shows rounded, spheroidal weathering. It is well exposed near the Sawmill and generally over O'Brien Park.

Wolsey shale.—The quartzite is overlain by shale, which is well exposed in Keegan Butte and the hill south of it which rises above the open and nearly level surface of Belt Park. The shale is dark gray or greenish, often micaceous, and carries oval concretions of limestone a few inches thick and seldom over 6 inches long. These concretions contain fossils which Mr. Walcott has identified as Middle Cambrian forms. These shales average 150 feet in thickness, and are well exposed at the old dam on Sheep Creek near Wolsey.

Meagher limestone.—The summits of Belt Park buttes are capped by thinly and irregularly bedded limestones. The rocks consist of pure gray limestone mottled with patches of buff-colored, arenaceous, clayey matter. The exposed edge of the beds shows wavy—almost crinkled—bedding planes. Over 60 feet of these beds are exposed on Keegan

Butte. The lower strata carry no distinguishable fossils, and weather into very small, irregular, gravelly débris. The upper beds are spotted with green glauconite grains and contain numerous fossil fragments.

Park shale.—The greater part of the Cambrian rocks seen in the mountain area probably belong to this formation. The lower strata are gray or greenish micaceous shales. Higher in the section these contain intercalated thin layers of limestones, which are impure and often consist of flat limestone pebbles—a true intraformational conglomerate (Pl. XXXIX, *A*). These beds are well exposed in the road cuttings at the head of Sheep Creek, in the valleys of Dry Wolf, Pilgrim, and Tenderfoot creeks, and near Barker. Their thickness is estimated at 800 feet.

Pilgrim limestone.—Above the Tenderfoot shale, whose ready weathering gives gentle slopes and generally open but deeply stream-trenched valleys, limestone beds form low cliffs or cap mesas on the broad summit levels of the range. These limestones are somewhat massively bedded. They are gray, carry fossil remains, and in this region do not show the mottled appearance common to rocks of this horizon in the southern part of the State. The basal beds are limestone conglomerates separated by thin layers of shale (see Pl. XXXIX, *B*).

Dry Creek shale.—Between the beds of massive Pilgrim limestone and the dark chocolate-colored beds of the Jefferson formation there is a thickness of 40 to 50 feet of brick-red and bright-yellow sandy beds, whose fissile nature determined their designation as shales. The formation is a very constant one throughout central Montana, but owing to its ready weathering is seldom well exposed. Good sections were observed at the head of King Creek, near Yogo, in Big Park, on Belt Creek above Monarch, and on Pilgrim Creek, the average thickness being 40 feet.

Yogo limestone.—This formation generally consists of thin-bedded limestone flags, alternating with crumbly gray or greenish shale, but grades into rather pure thick-bedded limestones. The entire section is well shown at the head of Sheep Creek and south of Monarch. A measured section made 8 miles south of that place is given in the description of that district (page 363).

Fossils.—These Cambrian formations have all been grouped as the Barker formation for the purpose of areal mapping. In former publications the series has been divided into two groups, the upper, or Gallatin, and the lower, or Flathead. This distinction was originally based upon the occurrence of the Pilgrim limestone, whose resistant nature and peculiar mottled character made it a very convenient horizon to use in areal mapping. The fossil remains seemed to indicate the Upper Cambrian age of the beds above this, but larger collections recently made by Mr. Walcott prove that the Upper Cambrian fauna is wanting in all the collections thus far made, the forms studied being all of Middle Cambrian types. The Lower Cambrian (Georgian Olenellus)

and Upper Cambrian (Potsdam) are both wanting. The sections shown on Pl. XL represent the strata of this age in the Little Belt Mountains, the Castle Mountain or Livingston sections being given for comparison.

Fossils are abundant in the limestone concretions of the Logan shale of Keegan Butte and in the thin-bedded limestone of the Wolsey shale at the head of Sheep Creek. The Pilgrim limestone at the head of King Creek also contains fossils, as do the Yogo limestones near Yogo settlement. The brachiopod species are few in number, and are associated with *Ptychoparia*, *Conocoryphæ*, and fragments of other trilobites, and an abundance of *Hyolithes*. Mr. Walcott, who has examined the collections, but not yet determined all the species, does not find any considerable differences of fauna from top to bottom. The following species have been identified by him:

Dicellomus nanus M. and H.	Pilgrim limestone, Yogo; Wolsey shale, Sheep Creek; Flathead quartzite, near Monarch and on Sheep Creek.
Obolus (Lingulella) ella	Wolsey shale, Sheep Creek.
Orthis remnicha	Yogo limestone.
Syntrophia primordialis	Yogo limestone.
Billingsella coloradoensis	Yogo limestone.
Hyolithes primordialis	Wolsey shale and Meagher limestone; Sheep Creek and Keegan Butte.
Ptychoparia gallatinensis	Pilgrim limestone, Pilgrim Creek.
Ptychoparia llanoensis	Yogo limestone.
Ptychoparia bipunctata	Yogo limestone.
Ptychoparia affinis	Yogo limestone.
Ptychoparia roemeri	Meagher limestone, Fourmile Creek.
Agnostus sp.	
Obolus (Lingulepis).	
Olenoides serratus	Wolsey shale, Sheep Creek.
Camarella	Wolsey shale, Sheep Creek.
Bathyuriscus Wheeler	Wolsey shale, Sheep Creek.

These forms are all regarded as Middle Cambrian by Mr. Walcott. They show local grouping, and very often individual beds are made up of an aggregate of one species. This is especially true of *Hyolithes* in the limestones of the Park shale and Wolsey shale, and of the *Ptychoparia gallatinensis* of the Pilgrim limestones of Pilgrim Creek.

SILURO-DEVONIAN ROCKS.

Jefferson limestone.—Upon the geologic map the Jefferson formation, under the name of Monarch formation, is grouped with the Threeforks shale, which carries Devonian fossils. Overlying the soft shales and associated limestones of the Cambrian there is a series of generally dark-colored, well-bedded limestones, whose lowest bed frequently forms a bold bluff or escarpment that rises abruptly above the shale slopes. The distinction is therefore usually a marked one in the topography, and is readily followed in mapping. This limestone bed is the basal member of the Jefferson limestone series.

As a whole the Jefferson formation is characterized by chocolate-brown or steel-gray crystalline limestones, generally having a distinctly granular or saccharoidal texture, which is especially noticeable on weathered surfaces. The rocks occur in beds 2 to 6 feet thick, which are jointed, and weather like regular courses of masonry (see Pl. XLII, *A*). Slight differences in hardness result in a pitting of the surface with sac-shaped cavities, due to weathering, and the edges of the beds often show ribbing and filagree work. The dark color is due to organic (nitrogenous) material, and the rocks emit a strongly fetid odor when struck with a hammer. The chocolate-colored beds are often mottled with light cream-colored patches, which in some instances are clearly recognizable as coral remains. The ledges near Barker show this especially well, as illustrated on Pl. XLII, *B*.

The only fossils collected from these rocks are corals. Mr. Charles Schuchert has identified *Diphyphyllum cæspitosum* Hall. In a report furnished the writer he says: "If this identification is correct the rocks are of Silurian (Upper Silurian) age. This genus, however, like *Atrypa*, is not always of great value as a horizon marker." Later collections from this horizon contained specimens of *Stromatopora*, *Pachyphyllum* (near *woodmani* H. and W.), and *Acervularia*, identified by Dr. Girty, and regarded by him as determining the age as Devonian. Up to the present no positive identification of Silurian rocks has been made in Montana. Frequent references to Silurian strata are made in the Hayden Survey reports, but the rocks therein called by this name are now known to be Cambrian. The uppermost beds of the Cambrian, the pebbly beds of the Yogo limestone, contain fossils which were formerly regarded as possible Silurian, but the only paleontological collections as yet thoroughly studied, those of the Yellowstone Park, prove to be Middle Cambrian. The nearest strata of undoubted Silurian age are those of the Bighorn Range of Wyoming.[1]

The Jefferson limestones contain much arenaceous matter, and at several localities elsewhere in the State grade into quartzite and sandstone. This is the case at Whitehall and Phillipsburg, Montana. At the latter place a collection of fossils showed the following species:

Camarotœchia sappho.
Camarotœchia near C. congregata.
Glyptodesma rectum?
Aviculopecten sp.
Cyathophyllum sp.

In a letter to the writer, Dr. Girty makes the following statement about the fossils determined by him from this locality:

> Although comparatively little has been ascertained in the way of certain and exact specific identification, yet I believe the horizon here represented can be referred with some certainty to the Middle or Upper Devonian. *Aviculopecten* has not been recognized in this country below the Devonian, but is abundant in deposits of Devonian and Carboniferous age. *Camarotœchia sappho* first appears in the

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[1] C. E. Beecher, on the occurrence of Silurian strata in the Big Horn Mountains, Wyoming, and in the Black Hills, South Dakota: Am. Geol., Vol. XVIII, 1896, pp. 31-33.

A. CHARACTERISTIC OUTCROP OF JEFFERSON LIMESTONES IN LITTLE BELT REGION; SUMMIT OF PLATEAU, AT HEAD OF KING CREEK.

B. CORALS IN JEFFERSON LIMESTONE.

The light cream-colored masses of coral mottle the dark-brown or black limestone.

Hamilton, but is known to extend into the Waverly. *C. congregata* is likewise a Hamilton form, as is also *Glyptodesma rectum*. This fauna can scarcely be earlier than Devonian, and I believe it represents middle or late Devonian time.

Threeforks shales.—The lighter-colored shaly limestones which immediately overlie the dark-colored Jefferson beds are known by this name. In the Little Belt Range the formation has not been distinguished from the strata which immediately overlie it, as the latter rocks are identical in lithological character, and were in the field mistaken for this formation. The beds cover the surface of the bench so often made by the massive limestone bed forming the top of the Jefferson. In this region the formation, if present, grades into and can not be distinguished from the upper beds of the Jefferson. On King Creek Mountain the shaly beds immediately above the typical dark-brown Jefferson limestone hold Carboniferous fossils, and this is also the case in the exposures a few miles east of Barker. The beds usually weather readily and the actual contact of the two formations is rarely seen. At Monarch the débris of the cliffs hides the lower beds, the interval being estimated to be about 60 to 75 feet.

It can not be asserted that the Threeforks shale is wanting over this region, but the collections from the shaly beds immediately overlying the typical Jefferson limestone contain Carboniferous fossils at several localities. In the vicinity of Livingston and near Threeforks the formation contains an abundant and typical Devonian fauna. In the description of Castle Mountain,[1] immediately south of the Little Belt Mountains, the limy shales at the base of the Madison limestone group was called Devonian, though no fossils were obtained from the beds; it now seems more probable that they represent the Paine shale of the Carboniferous.

CARBONIFEROUS ROCKS.

The Carboniferous rocks are the mountain-forming strata of the range. Their occurrence sharply defines the mountain area from the surrounding plains, and determines the rough and craggy character of the scenery of its border. Fossil remains, which are abundant throughout the series, show the rocks all to be of Lower Carboniferous age.

The collections afford some evidence upon which to subdivide the series by faunal groupings. There is, also, a very marked grouping of the beds shown by lithological characters. The lower series, embracing a thickness of 1,000 feet of beds, is composed entirely of limestones of varying character. This is the Madison limestone of the geological map, a formation that is very persistent in occurrence and very uniform in character throughout central Montana. This limestone terrane is overlain by a series of shales, sandstones, and limestones, collectively known as the Quadrant formation, and the equivalent of this formation is developed in the southern part of the State, though presenting a very different development in this area.

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[1] Bull. U. S. Geol. Survey No. 139, p. 38.

MADISON GROUP.

This embraces three lithologically distinct horizons, viz:

3. Castle limestones.
2. Woodhurst limestone.
1. Paine shales.

Paine shales.—These are dark-blue, quite impure, argillaceous limestones, which might be classed as calcareous shales. The fresh rock is generally dark bluish-gray, but lighter-colored beds alternate with this. Upon weathering, the rock breaks up into fine shaly débris of a pink, buff, or straw color. The exposures of the lower beds form typically reddish or pink débris, and the weathered surfaces show an abundance of fossils, usually weathered in relief. The beds higher in the series and near the top contain fewer fossils, but the forms are silicified, beautifully preserved, and project above the smooth weathered surface in a very striking manner. This silicification appears to be a very constant feature of this particular bed throughout the mountain region, and when carefully looked for has always been found by the writer. These strata show 6 to 30 inch beds of rather pure limestone, containing chert lenses one-half inch by 3 inches, separated by 3 to 10 foot beds of light-buff, varying to pink and dark bluish-gray limestone shale. The total thickness at Monarch is 175 feet. The ready weathering of these shaly beds gives rise to topographic depressions and vegetation bands, so the horizon is easily determinable (see Pl. XLIII; *A*, Monarch exposures; *B*, Barker exposures.)

This limestone is especially distinguished by an abundance of Bryozoan remains. The following table gives the list of species identified by Mr. Charles Schuchert, of the National Museum. The numbers refer to localities from which collections were made by the writer. This formation is undoubtedly the same as that called by Dr. A. C. Peale the Laminated limestones of the Threeforks section.[1]

Fossils from the Paine shales.

	642.	301.	294.	603.	604.	550.	552.	560.	545.	608.
Aulopora sp	....	....	....	....	....	....	....	....	....	....
Spirorbis 2 sp	....	....	....	....	....	....	....	....	....	....
Fenestella (several species)	×	×	....	×	....	×	×	....	....	....
Cystodictya sp	×	×	....	×	....	....	×	....	....	....
Streblotrypa sp	....	....	....	....	....	....	....	....	....	....
Pinnatopora sp	×	×	....	....	....	×	....	....	....	....
Crania (striated species)	×	....	....	....	....	....	....	....	....	....
Rhipidomella michelini l'Év	....	×	×	....	×	....	....	×	....	....
Orthothetes inflatus White and Whitf.	×	....	....	....	....	....	....	....	....	....
Chonetes sp	....	....	....	....	....	×	....	....	....	....
Productus lævicosta White	×	....	....	....	....	....	....	....	....	....

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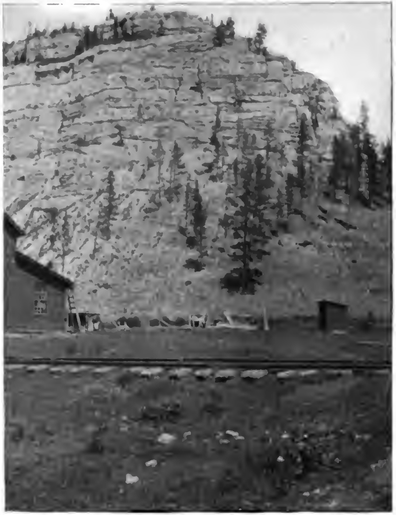
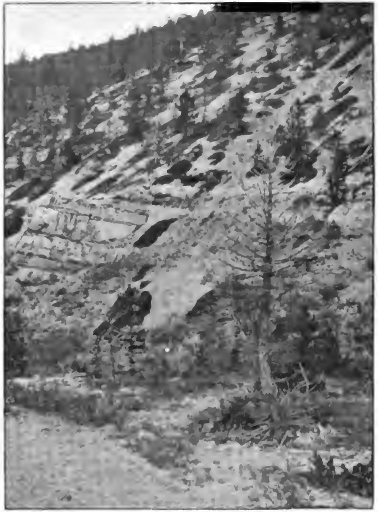
[1] Bull. U. S. Geol. Survey No. 110, 1893, p. 33.



A. LIMESTONE CLIFFS AT MONARCH.

The Paine shale forms the base of the cliff and the slope beneath.



B. OUTCROP OF PAINE SHALE ALONGSIDE WAGON ROAD 4 MILES EAST OF BARKER

The shaly nature of the formation and its usual weathering are contrasted with the masonrylike ledges of the underlying Jefferson limestones.

Fossils from the Paine shales—Continued.

	642.	301.	294.	603.	604.	550.	552.	580.	545.	608.
Productus cf. setigerus Hall	....	....	....	×	×	....	×	....	×	....
Spirifer centronatus Winchell	×	....	....	....	....	....	....	×	....	....
Spirifer striatus Martin	....	×	....	....	....	....	....	....	....	....
Spirifer desideratus Walcott	....	×	×	....	....	....	....	....	....	....
Reticularia setigera Hall	×	....	....	....	....	....	....	?	....	....
Spiriferina transversa McChesney	×	×	....	....	....	....	....	....	....	....
Spiriferina (allied to S. norwoodana), Hall	×	....	×	....	....	....	....	....	....	....
Cyrtina (related to one from the Waverly group of Richfield, Ohio)	×	....	....	....	....	....	....	....	....	....
Cleiothyris hirsuta Hall	×	....	....	×	×	....	....	×	×	....
Eumetria sp.	×	....	....	....	....	....	....	....	....	....
Dielasma formosum ? Hall	×	....	....	....	....	....	....	×	....	....
Camarophoria (related to C. explanata McChesney)	×	....	....	....	....	....	....	....	....	....
Pugnax mutata Hall	....	×	×	....	....	....	....	....	....	....
Camarotœchia cf. metallica White	....	....	....	×	×	....	×	....	....	....
Gasteropoda, 5 sp	×	....	....	....	....	....	....	....	....	....
Euomphalus spergenensis Hall	....	....	....	....	....	....	....	×	....	....
Bucanopsis textilis ? Hall	....	....	....	....	....	....	....	×	....	....
Conularia sp.	....	....	....	....	....	....	....	×	....	....

642. Divide between Dry Fork of Belt Creek and Belt Creek north of Barker trail.
301. Mountain at head of Harrison Creek.
294. Cliffs at head of King Creek.
603. Southeast base of Big Baldy Mountain.
604. Big Park section of Big Baldy Mountain.
550. Mouth of Bear Creek.
552. Near mouth of Bear Creek.
580. Divide at head of Running Wolf Creek.
545. Divide between Running Wolf Creek and Bear Creek.
608. Saddle northeast of Taylor Peak.

Woodhurst limestone.—The middle portion of the limestone series is composed of well-bedded limestones. The strata vary in thickness and in resistance to weathering, so that the steep slopes show the harder beds as prominent ledges, and on escarpments these are undercut and form balcony ledges, which give a banded appearance to the cliffs. The series is shown as a magnificent line of cliffs from 300 to 600 feet high, exposed for many miles along Belt Creek, above and below Monarch (see Pl. XLIII, *A*). The cliffs are stained a bright orange color by iron oxide, and this makes the contrast with the overlying white limestones stronger. This coloring comes from extremely thin partings of shaly material separating the beds. These partings also serve to emphasize the bedding planes. The rocks are prevailingly dark gray or gray, and break readily into angular, splintery, polygonal débris, forming extensive talus heaps. The outcrops of each bed are distinguished by a jointed masonry-like course. Chert occurs in many strata, but apparently without any order. It weathers dark brown, and often occurs in layers.

The following table shows the fossils collected from the Woodhurst limestone in this region. The identifications have been made by Mr. Schuchert.

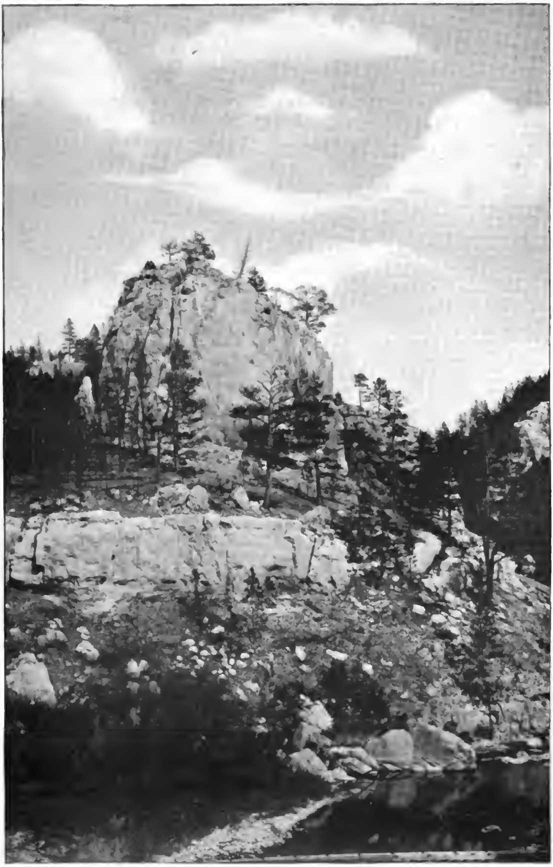
Fossils from the Woodhurst limestone.

	545.	547.	553.	554.	558.	561.	577.	585.	593.	597.	609.	650.	649.	648.	401.
Platycrinus sp															
Tæniodictya ramulosa Ul						×									
Rhombopora dichotoma Ul														×	
Rhipidomella (small michelini l'Év						×								×	
Schizophoria swallovi Hall								×							
Orthothetes inflatus? White and Whitf		×	×	×	×	×		×	×	×		×		×	
Derbya sp. undt															
Chonetes illinoisensis Worthen														×	×
Chonetes loganensis H. and W.	×	—	×	×	×	—	×	—	×	×	×	—	—	×	
Productella shumardiana Hall															×
Productus—cora group															×
Productus lævicosta White	×											× ?		×	
Productus cf. setigerus or scabriculus			×	—	—	×									
Productus cf. gallatinensis n. sp.														×	×
Spirifer cf. biplicatus Hall															×
Spirifer centronatus Winchell		×	—	—	×	×	×	×	×	—	—	×	×	×	
Spirifer trigonalis Martin															×
Reticularia n. sp														×	
Reticularia setigera Hall														×	
Martinia rostrata n. sp.														×	
Syringothyris cf. extenuatus Hall							×								
Spiriferina cristata Schlot															×
Spiriferina transversa McChesney		×	×	×	—	—	—	—	×	—	×	—	×	—	—
Spiriferina solidirostris White							×								
Seminula trinucleus Hall	—	—	—	—	×	—	×	—	—	×	—	—	—	—	×
Cleiothyris crassicardinalis White				—										×	
Eumetria marcyi Shum					×	×			?					×	
Camarotœchia cf. metallica White	—	—	—	—	×	×						×			
Platyceras sp				×											
Euomphalus luxus White			×	—	—	×	—	—	×						
Prœtus peroccidens Hall and Whitf													×		

The numbers at the heads of columns in the above table refer to localities at which collections were made. The specimens are now in the National Museum and may be identified as to locality by the numbers. The dashes in the table mean that species are probably present at the points indicated, though they are not represented in the collection brought in.

A comparison of the two tables shows that a number of species occurring in the Paine shale have not been found in the overlying limestone, viz:

Fenestella, several species.
Crania, striated species.
Spirifer striatus Martin.



GIANT ROCK, BELT CREEK CANYON BELOW MONARCH.

Showing the massive bedding of the Castle limestone of the Madison group. Lower Carboniferous terrane.

Spirifer desideratus Walcott.
Cyrtina.
Cleiothyris.
Camarophoria cf. C. explanata McChesney.
Pugnax mutata Hall.
Camarotœchia cf. C. metallica White
Gasteropods, 5 species.
Euomphalus spergenensis Hall.
Bucanopsis textilis Hall.
Conularia sp.

Of these, *Cleiothyris hirsuta* seems to be especially characteristic. *Reticularia setigera* extends into the basal beds of the Woodhurst limestone. The collections from this basal bed of the Woodhurst embrace seven species not found at any other locality. The species common to both formations are the most abundant types and comprise the bulk of the collections. The faunal differences may be due entirely to the character of the rocks. The Paine shale was a calcareous mud deposited in shallow waters, while the overlying limestones are very pure and indicate clear waters.

The collections, as a whole, are referred by both Schuchert and Girty to the Kinderhook or Chouteau. This is entirely in accord with the results obtained by them from a study of the fossils from the vicinity of Threeforks, described by Peale,[1] and from a study of those of the Carboniferous areas near Livingston collected by the writer.

Castle limestone.—The uppermost formation of the limestone series is a limestone that is very massive and shows no bedding. The rock is generally dense and rarely crystalline, always light colored, and in exposure shows inconspicuous division planes. It weathers with a rough cavernous surface, forms castellated craggy masses, and is easily distinguished from the well-bedded rocks beneath it. The type of erosion is illustrated on Pls. XLIV and XLV. Its massive homogeneous character causes it to form very narrow canyons, and it is the "gateway" rock of the mountain streams. It is frequently crushed and brecciated when folded, and in such cases often stained red by iron oxides, which are sometimes so abundant as to cause prospectors to locate claims. The rock contains dark-brown chert scattered through it in round and lenticular masses, sometimes a foot in diameter, but the chert is light colored and not abundant enough to be conspicuous in most exposures. The beds cap the great cliffs of Belt Creek and are everywhere prominent upon the mountain flanks. The formation takes its name from the town of Castle, where it is especially well developed. The thickness measured near Monarch is 375 feet, and at several localities throughout the mountains it is 300 to 400 feet.

The following section represents the typical development of the Madison group in this region. It does not embrace the base of the Paine shale, and it is possible that a few feet may be wanting at the top.

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[1] Bull. U. S. Geol. Survey No. 110.

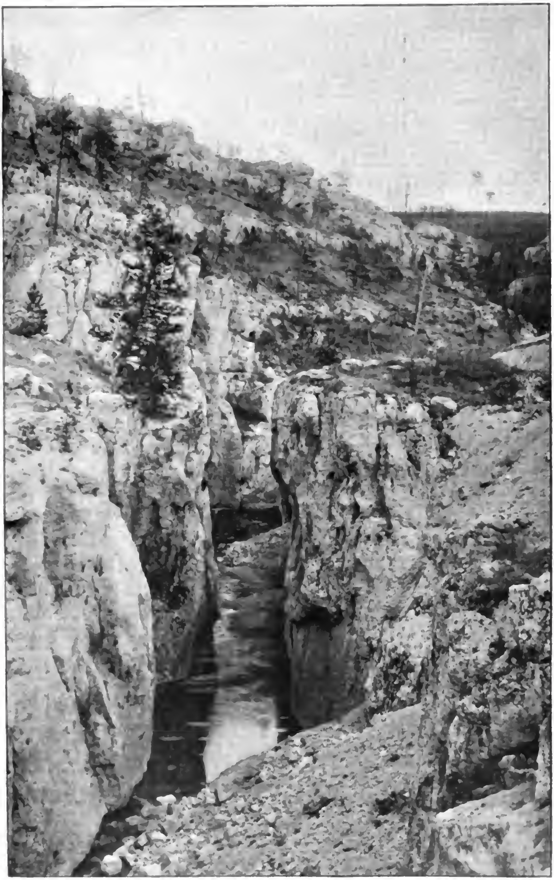
This section should be compared with that, given with the description of the Monarch district, of the cliffs near Monarch.

Section of Carboniferous limestones exposed in cliffs north of Dry Wolf Creek, 1 mile above Spring Coulée.

	Feet.
Castle limestone:	
Limestone; brownish gray in color, often conglomeratic	5
Limestone; cream colored, blotched with pink	2
Limestone; massive, but brecciated in places	115
Limestone; gray, somewhat massive, and forming bench on summit of buttress spurs	30
Well-bedded limestone, dark blue in color, weathering to buff gray; carrying chert bands of one-half inch to 2 inches in thickness at 40 feet above base; generally heavy bedded with vertical jointing and breaking into small prismatic pieces	170
Limestone; gray, massive, belonging to same series as that above	10
Woodhurst limestone:	
Limestone; quite massive, heavily bedded or without recognizable bedding, weathering into rude prismatic blocks and forming buttresses projecting from steep slopes north of creek. The upper 75 feet shows rude bedding, with chert bands and drusy cavities scattered through the rock. Crinoid stems are abundant and other fossils are occasionally seen	250
Limestone; gray, quite massive	15
Limestone; massive, with indistinct bedding planes and rude prismatic fracture and irregular surface, and carrying scanty crinoid remains	60
Limestone; thick and thinly bedded, quite massive in exposure, breaking into splintery fragments and showing occasional fossils	65
Paine shale:	
Thin bedded limestone, brownish or buff color on weathered exposure, with argillaceous layers of fissile limestone 2 to 6 inches in thickness between the purer and more massive beds. The rocks form buttresses with square jointing, vertical faces, and a masonry-like appearance	85
Thin-bedded, shaly limestone	10
Limestone; gray, weathering with rough surface and forming ledge above talus slope	8
Limestone; thin bedded (4 inches to 2 feet), alternating with shaly limestone beds a few inches in thickness	27
Débris concealing base of exposure and running down to creek	80
Total	932

QUADRANT GROUP.

Above the massively bedded white limestones, which nearly everywhere form the flanks of the range, there is a series of sandstones and shales with intercalated limestones that weather readily and form the narrow foothill hollows between the mountain slopes and flanking hills of sandstone. This series is collectively named the Quadrant formation or group, as it corresponds in stratigraphic position and in the changed conditions of origin which it represents to the formation given that name in the southern part of the State. In these mountains the shales and limestones of the formation contain an abundance of fossils which belong to the Lower Carboniferous, and these forms extend through the formation up to its very top. There is, however, evidence of an unconformity between this and the succeeding Jurassic formation. As noted above, the beds occur chiefly as an encircling



SLUICEBOX CANYON, BELT CREEK

Showing massive character of Castle limestone. Also illustrating cutting of secondary canyon—"Sluicebox"—in an older and broad valley

belt about the mountains, but inliers formed by synclines also occur within the mountain tract at Bear Park and between projecting ridges of the range at Lone Tree Park and the divide west of Taylor Peak. The Quadrant group consists within the Little Belt region of two sets of beds.

Quadrant group:	Feet.
Otter shale[1]	300–600
Kibbey formation	115–150

The total thickness is 313 feet on Dirty Creek, 303 feet in Musselshell Canyon, 453 feet at Riceville, and 1,400 feet near Utica.

Kibbey sandstone.—The basal member of the Quadrant group is a sandy formation which is commonly brick-red in color, is seldom well bedded, and weathers quite readily. Where best exposed it is seen to consist of slightly indurated sandy clays, prevailingly red in color, with lumps of yellowish clay scattered through it. This grades upward into a well-bedded, somewhat fissile, red and purple sandstone. These beds are best developed near Kibbey and Riceville, where they contain intercalated gypsum beds. The thickness here is 150 feet.

West of Utica, at the forks of the Judith, the lower clays are 75 feet thick and the sandstones 40, giving a total of 115 feet for the formation. At the east end of the range, at Oka, the beds form an encircling hollow between the main mountain mass and an outlying limestone hill. In Musselshell Canyon the formation is thin, the basal bed being but 15 feet thick. These beds immediately overlie the massive Castle limestones, and are therefore readily located, though seldom exposed. Near Woodhurst and north of Dry Wolf the beds are gray, varying to buff, in color. No fossils have been found in these beds.

Otter shale.—This formation consists of green and gray shale, with intercalated limestones. The green shales form its most conspicuous feature. They are bright coppery green in color, and where well exposed are very striking features of the canyon walls. The interbedded limestones are thinly bedded, white or light gray in color, but are often markedly oolitic. They carry Carboniferous (Mississippian?) fossils. The variable nature of the formation is shown in the detailed section near Utica, given herewith, but the details differ greatly in different exposures, though the general character is constant. The thickness at Riceville is 300 feet; at Musselshell Canyon and Dirty Creek it is much less.

Fossils.—The fossils from the Quadrant group are abundant at several localities, but only small collections have as yet been made. The collections from Riceville are different in form from those of any other locality, the species showing a Spergen Hill facies. The following species from this place have been determined by Mr. C. D. Walcott:

Seminula subtilita Hall.
Eumetria marcyi Shum.
Pugnax mutata Hall. (Common.)
Euphemus carbonarius Cox.

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[1] Named in 1891. See Two Montana coal fields: Bull. Geol. Soc. America, Vol. III, 1892, pp. 301–330.

Dielasma cf. formosa Hall. (Common.)
Seminula cf. trinuclea Hall.
Eumetria verneuiliana Hall.
Spiriferina cf. cristata Schl.
Allorisma sp. undet. (Like marionesis.)
Schizodus curtiformis Walcott.
Euphemus sp. undet.
Lophophyllum sp. ?
Stenopora sp. ?

The following species, identified by Mr. Charles Schuchert, were collected from the Forks of the Judith, west of Utica:

Cytherella sp. ?
Anomphalus sp. ?
Orbiculoides sp. ?
Derbya sp. undet.[1]
Seminula cf. trinucleus.
Productus semireticulatus Martin.
Spirifer keokuk Hall.
Nucula like parva but larger.

On the southern flank of the range from Dry Fork of Belt Creek fossils obtained from the fissile limestones but a few inches below Jurassic fossils show a fauna differing from any found elsewhere. Mr. Schuchert says: "The evidence, however, is such that no definite age can be assigned to this fauna closer than Carboniferous, and apparently Lower Carboniferous."

Productus semireticulatus Martin.
Seminula sp. undet.
Dielasma sp. undet.

SECTION ON JUDITH RIVER NEAR UTICA.

The following section, which was measured in the foothills west of Utica on the Judith Basin, near the Sapphire mines, represents the lithological characters of the formation. Owing to several landslips, there is a little doubt about the thicknesses given for the upper part of the section, which may be excessive.

Section of Carboniferous shales, Jurassic and Kootanie beds, exposed on north side of Judith River near Utica.

	Feet.
Kootanie:	
Black shales	?
Red earths, alternating with 3-foot beds of sandstone	100
Sandstone, massive and everywhere prominent	40
Red earths	?
Buff sandstone	3
Red earths	50
Sandstone	5
Sands	50-75

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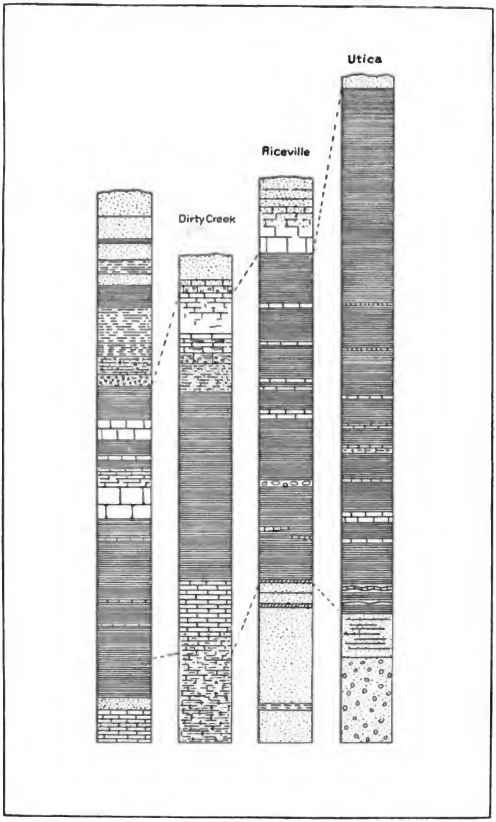
[1] Very abundant. A similar form occurring in the St. Louis formation is often identified with the Upper Carboniferous *D. crassa*. There are differences, however, between the two forms.



COLUMNAR SECTIONS OF THE FORMATIONS OF THE QUADRANT GROUP, OF LOWER CARBONIFEROUS AGE, IN CENTRAL MONTANA

Scale: 1 inch = 110 feet.

First column represents section exposed in canyon of north fork of Musselshell River above Martindale

The two broken lines running between the columns divide them into three portions, of which the upper one represents the Ellis (Jurassic) formation, the middle the Otter shale and the lower the Kibbey sandstone

Rectangular block patterns represent limestone, close lining represents shale, stippling represents sandstone.

	Feet.
Jurassic:	
Limestone; white, earthy	5
Red earths and shales	55
Limestone changing to sandstone; sometimes a conglomerate; carries fossil gryphæas	20
Sandstone; fissile, breaking into plates one-half to 1 inch thick	3
Sandstone; brown; contains typical Jurassic (marine) fossils	15
Carboniferous-Triassic:	
Sand and red earths	?
Limestone; white	3–5
Red earths	
Sandstone; white, with local lenses of earthy, light-buff limestone and gypsum, quartz crystals, and locally with conglomerate and 6-inch balls of banded chert	25
Red sandstone	30
Limestone; thickly and thinly bedded, hard, dense, gray to dove-colored rock; not crystalline	30
Limestone; massive bed of rough weathering, gray limestone	3
Limestone; débris shows minute gasteropods	65
Limestone; thin bedded	5
No exposure	25
Sandstone; red, earthy, fissile	2
No exposure	8
Sandstone; granular, friable, soft rock with massive, round-weathering outcrop	10
Sandstone; red	6
No exposure	200
Limestone; marble-like and weathering into reddish-colored bits	200
Limestone; yellow, weathering with rough, prickly surface	2
No exposure. Soil holds small masses of a purple-colored limestone, breaking into fine débris	140
Dark-red sandstone; locally a conglomerate, generally red	55
Limestone; white to dove colored, shaly, breaking in plates a foot square and one-fourth inch to 2 inches thick, weathering pink or lavender colored, and into red earths. Carries minute gasteropods	?125
Sandstone; granular saccharoidal, buff to yellow, varying to white and pink, or red at top. Dip 10°; forms bench	45
Shales; thin-bedded gray shale and impure limestone; drift of massive white limestone, breaking into blocks 3 feet square, covers surface, but was not seen in place. These beds, of which 100 feet are exposed in gully, resemble the Jurassic	200
Limestone	7
Shale; dark gray, calcareous	25
Shale; light green	10
Shale; purple	4
Shale; greenish white	1½
Green shale series:	
Minette sheet, with 1 foot of altered shale at contact.	
Green shale	10
Oolitic limestone	1
Green shale and purple shale	15
Hornstone, or dark-colored altered limestone, weathering light	2
Minette sheet	10
Shale; green	15
Limestone; white and massive	5

Green shale series—Continued.	Feet.
Shale; black	20
Limestone; pearl gray, dense and compact	3
Shale; greenish gray, soft and crumbly	20
Limestone; dense, jasper-like in texture, massive	6
Limestone; buff, with earthy yellow staining	4
Shale; crumbly and breaking into fine bits	22
Limestone; white and massive	3
Shale; not exposed	25
Limestone; white, massive, and dense, very hard and rarely crystalline	12
Shale; soft, gray, and earthy	15
Limestone	5
Shale; fissile or in plates one-half to 1 inch thick; gray-colored shale, alternating with soft, more earthy shale, with harder scalloped layers	75
Sandstones; light-purple, gray sandstones and sandy earths, with shaly belts of 6 inches to 2 feet	40
Red (magnesian) earths, mottled and spotted one-half inch with green. Represents knotted or lumpy beds seen along base of Little Belt Mountains and at Oka	75
Massive white limestones.	

CHAPTER III.

DESCRIPTIVE GEOLOGY OF THE SOUTHERN AND JUDITH AREAS.

INTRODUCTORY.

In the following pages a detailed description of a large part of the Little Belt Range is given. A very brief summary of these facts has already been presented in the general account of the range and of its rock formations, but it is believed that the detailed descriptions will be useful to those who may desire to know more of the geology of particular parts of the range, especially of those districts where mineral resources are from time to time reported. For this reason the descriptions, though summarized from notes taken in the field, are yet somewhat full, particularly as an effort has been made to make the account of each district complete in itself, necessitating an occasional repetition of facts previously mentioned. The observations on which the descriptions are based were made in the summers of 1893 and 1894, and during brief visits to Neihart in 1895 and 1897, while the mapping of the areal geology of the region was in progress.

For the purposes of description, the region has been somewhat arbitrarily divided into five districts, of which four have been named from the prominent settlements of the area. The first embraces the entire southern part of the mountains, in which there are few prospects and no productive mines. It includes the country drained by the Judith River and by Sheep Creek. The four other general divisions made are designated the Yogo, Neihart, Monarch, and Barker districts. The subheadings given in the description and in the table of contents will inform the reader as to the district in which a peak or valley has been placed, if in doubt.

SOUTHERN PART OF RANGE.

The relatively simple structure and broad topographic features of the southern part of the mountains have led to its treatment under one general heading. In this part of the range the relation between topographic form and geologic structure is most strikingly illustrated. The mountains are parts of the great broad and flat fold of the range, cut by streams and erosion into individual summits. The gentle slopes of the plateaus of the Judith and those of the higher mountain ridge forming the east end of the range follow the inclination of the easterly dipping beds of Paleozoic rocks which form their surface. The broad sheets of these limestones are seen covering the summits or lying in overlapping plates upon the outer flanks like the shingles on a roof. The region shows no evidences of glaciation, not even by those small and local ice pockets so common in the Rocky Mountain region during Pleistocene time. Therefore the topographic features and scenery are due to erosion alone, and there is a marked contrast between the areas where soft rocks cover the surface and those covered by a harder, more resistant material.

EAST END OF RANGE.

The eastern end of the range loses the broad plateau character which prevails farther west, and narrows to an anticlinal ridge that terminates abruptly at Júdith Gap, a few miles east of the limits of the area shown on the accompanying map, Pl. XXXVI. This secondary range is a low mountain mass, whose dark forest-clad slopes and white limestone cliffs are in strong contrast to the surrounding plains. The highest summit is a flat-topped elevation whose westward-facing cliffs make the name Bluff Mountain an appropriate one. From this point eastward the range declines very gradually. There are no sharp peaks, and the only individual summits are the two known as the Twin Peaks.

Foothills.—To the south the mountain tract is flanked by a very narrow belt of foothill ridges and an outer plain whose gently sloping, uniformly level surface extends southward to the meadows of the Musselshell River. North of the mountains the foothill tract is wider, the ridges forming pronounced topographic features and inclosing a basin of considerable extent.

The inclined plain about the mountains is a feature common to most ranges of the State. It is underlain by soft and easily eroded shales and sandstones of Cretaceous age, leveled by the streams from the mountains to broad plantation terraces. Seen in profile this tract appears to consist of a number of terraces of different levels whose front is deeply trenched by lateral drainage ways and crossed by the larger mountain streams.

Structure.—The structure is simple, this end of the range being an anticlinal arch whose axis pitches eastward, so that the range declines in height in that direction, and ends where the massive limestone beds pass beneath the plains. This structure may be compared to an inverted canoe whose prow forms the hills east of Twin Peaks. The rocks thus uplifted and folded are all of sedimentary origin, and in the mountains are all of Paleozoic age. Upon approaching the mountain area the slopes are seen to be sheathed with great curving plates of limestone, cut into scallops by the streams that trench the slopes. Traveling up any of the larger drainage ways, the strata are seen to dip away from the mountains. The inclination is slight, not over a few degrees upon the outlying terrace plain, but gradually increases as the mountains are approached, until it becomes 20° to 30° in the foothill tract.

Continuing up the stream way, this dip increases until, in the narrow gorges cut in the limestones, it is generally 30° to 40°. If one continues up the gorge, he will find that the dip gradually lessens until the beds are nearly flat upon the summit, or dip at a low angle to the eastward—that is, with the range and not away from its axis. The same structure will be found on the opposite side of the range, so that a cross section would show the structure to be that of a flat-topped arch with steeply sloping sides.

The creek whose broad valley cut into the open plain is known as Hopleys Hole, shows in the foothill tract excellent sections of the beds which overlie the great limestone series. A section at this locality showed the usual development of the Quadrant formation and overlying Jurassic beds, but the overlying Cretaceous rocks which form the outer part of the foothills were not well enough exposed to warrant its subdivision into the formations recognized farther north.

Dirty Creek section.—The stream known as Dirty Creek affords good exposures of the Quadrant formation, and the following section was measured:

Section on Dirty Creek.

	Feet.
Cretaceous conglomerate.	
Softer shaly beds.	
Jurassic:	
Sandstone; coarser, less firmly cemented, generally reddish; forms surface of slopes and crest of hill	35
Sandstone; yellow weathering, well bedded and cross bedded, carrying large gryphæas	
Conglomerate (1 to 1½ feet), formed of chert nodules and limestone pebbles, arranged flat	
Carboniferous:	
Limestone; light brownish-gray, carrying black flints; dense, not crystalline, massive, 3 to 6 foot beds; no fossils in lower 20 feet, but abundant in more fissile and shaly, yellow-weathering limestone forming upper part	35
Limestone; dark-blue, in 2 to 3 foot beds, alternating with 3 to 12 inch beds of shaly limestone, carrying fossils	18
Limestone; light-gray, heavily bedded, carrying dense black chert	10
Shales; light earthy colored and green, in part sandy	200
Limestone; black and shaly, changing to dense blue limestone above	50
Shales; with interbedded impure sandstones and red clays at the base	100
Limestone; dense, massive, nearly white, not crystalline, carrying white chert in layers and nodules	15
Massive Carboniferous beds.	

As the uplift of the range increases westward, erosion exposes the older nucleal rocks of the fold on the very summits west of Bluff Mountain. The thickness and relative positions of the different formations are best seen in the stream gorges, but these are generally too narrow and precipitous for travel, especially where cut in the limestone series, and it is easier to follow the summit of the ridges. Upon crossing the rough outcrops of the Carboniferous, on which an abundant growth of pine flourishes, an open grassy sag or depression is found to mark the presence of the shaly beds. From the base of the Madison formation to the summit of the range there are mountain meadows and groves of pine, and as one ascends the slope the low step-like outcrops of the dark-colored Jefferson limestone give place to the smooth slopes and rich herbage of the Cambrian shales.

The strata on the summit have a gentle easterly dip of about 2° to 3°, and this may be assumed to represent the pitch of the axis of the range at this point. The exposures of Cambrian shales capped by limestones in Bluff Mountain show, however, that the average pitch of the axis is 1° 30′, calculated on the basis of the known thickness of the strata and their elevation at the east end of the range.

Bluff Mountain.—Bluff Mountain presents the most striking section of the general anticline to be seen in the range. Its steep western face shows several hundred feet of greenish micaceous Cambrian shales, with interbedded limestones, capped by the heavy bed of limestone which forms the cliff at the top and whose débris litters the slopes. Seen from the west these beds form an arch in Twin Peaks. The outlook from the summit is extensive and affords a comprehensive view of the entire southern and eastern portion of the range. To the west the broad plateau summit is notched by a depression cut through to the gray shales of the Belt formation, the nuclear core of the range. Beyond this the plateau character is more marked and continues westward for many miles. To the north the anticline is seen to be deeply cut by the South Fork of the Judith. The main stream penetrates to the Belt formation, but the resistant sandstone that forms the base of the Cambrian covers extensive tracts, forming a densely wooded plateau level. Beyond the South Fork of the Judith the slopes show the exposed edge of the beds that underlie the Lost Fork Plateau, the beds dipping at an angle coinciding very closely with the slope of the plateau surface.

NEWLAND CREEK HILLS.

The low submountainous tract drained by Newland Creek is the southern extension of the Little Belt Range. The topography is in strong contrast to that of the range proper, where the later Paleozoic rocks prevail. It is an open country, with well-rounded hills, gently modeled slopes, and broad summit levels. The streams cut the rocks readily and erosion is rapid. Over large areas the country is treeless, shows little or no soil and a scanty growth of grass.

The Belt formation includes several horizons, and these are well developed in this region. The Newland limestones form cliffs bordering the creek meadows, and the brick-red shales which locally form the top of the Belt terrane are well developed, weathering in gullies that separate the hills of drab shale from the wooded ridges formed by the outcrops of the Flathead quartzite.

Igneous intrusions.—The shaly beds of the Belt formation are easily penetrated by igneous intrusions, but within this part of the range only a few unimportant masses of igneous rock are found. Several of these are seen in the slopes bordering Newland Creek, their occurrence being shown on the geologic map. Near the fork of the road on the north side of the creek the shales, which dip downstream at an angle of 18° to 20°, are penetrated by a small mass of hornblende-mica-porphyry. The rock is platy, occurs as an intrusive sheet conformable with the shales, and is apparently sheared by its upheaval with them. The porphyry is greatly altered.

A mile below the point just indicated a white or straw-colored rhyolite-porphyry is encountered, the débris of which forms a slide along the slope. The rock is much decomposed and shows little quartz crystals scattered through a fine-grained groundmass, and several small exposures occur on the southern side of the creek. The intrusive rocks do not disturb the general structure of the sedimentary beds nor produce any appreciable metamorphism of the inclosing shales. Farther down, the valley has been cut across the upturned Cambrian rocks. The basal quartzites are separated by a bed of shale into which a variety of granite-porphyry of rather fine grain has been intruded. The weathered surface is somewhat rough and pitted and shows only round quartz grains, but the fresh fracture shows glassy crystals of quartz an eighth of an inch across, small yellowish feldspars, and larger, tabular crystals of clear orthoclase a half inch or more across.

North of the creek the Cambrian sandstones change their course, and the ledges extend along the slopes a few hundred feet above the creek. The overlying Cambrian limestones are cut through by the creek, the ledges dipping downstream. These rocks are intruded by a mass of granite-porphyry that does not disturb this general dip. The rock is fine grained, platy near the contact, and weathers in massive outcrops. Below this intrusion the limestones appear, with the same general dip of 25°, the strike being N. 55° W., or nearly at right angles to the creek valley. A small lateral drainage cutting into the west end of the ridge marks the approximate location of a fault which extends from the mouth of Fourmile Creek, north of Castle Mountain, along the limestone hills and ridges north of the Smith River Valley to this place. This fault, though not so profound as the one that defines the northern border of Smith River Valley north of White Sulphur Springs, is yet an important element in both the geology and the topography of the region, though the area affected lies outside of the region under immediate discussion. Beyond the fault the limestones exposed on the slopes bordering Newland Creek are also of Cambrian age, but strike N. 20° E., and dip at 10° to 15° upstream.

North of Newland Creek Valley a broad, undulating summit extends to the borders of Sheep Creek Valley. This tract shows the gray shales and limestones of the Belt formations, which are intruded by sheets of porphyry a few miles south of the sharp, forested eminence called Coxcomb Butte (Black Butte). At the south base of this butte the rocks show local induration and are puckered and wrinkled, but the general strike is east and west, and the dip 60° to the south. The stratigraphic throw of the fault is at least 3,000 feet, as that thickness of beds is wanting between the quartzite and the Newland limestones. The fault must be as great as this, even if the quartzite is Cambrian and not Algonkian in age.

SHEEP CREEK VALLEY AND VICINITY.

Sheep Creek is the largest of the streams draining the western slope of the range and emptying into Smith River. The wagon road from White Sulphur Springs crosses the broad meadows of the low divide between Newland and Sheep creeks, and follows the latter stream through a broad valley to the pass across the range at the head of the stream. For several miles below this pass Sheep Creek flows over the bedded rocks in the direction of their dip, then, turning westward, has a course nearly coincident with the strike of the rocks. Below this broad strike valley the stream enters a canyon cut across upturned quartzite beds and descends with rapid grade through a narrow gorge cut in gneisses and schist.[1]

The geologic structure is as simple as that of the plateau country of the Judith. The stream follows a valley cut into a block of slightly tilted sedimentary beds, dipping southward from the parks of Belt Creek to the profound fault which bounds the mountains on the south, and brings up the lower formations of the Algonkian against Cambrian rocks. The strata have been eroded into connected but individual blocks and the valley cut in soft shales of the Cambrian and Belt terranes, whose underlying quartzites form the resistant beds that have determined the presence of the broad, park-like valley. There are several hay ranches in the bottom lands, at one of which the post-office of Wolsey has been established for many years.

SMOKY MOUNTAIN.

South of Sheep Creek dark wooded slopes rise steeply to the ridge whose highest summit is Smoky Mountain. This mountain block is formed of beds inclined southward at gentle angles, varying between 3° and 5°. The Cambrian quartzites exposed in the valley floor near Wolsey pass beneath the slopes, the overlying shales being concealed by the soil and vegetation. At 950 feet above Sheep Creek the low ledges of the brown and black Jefferson limestones form low reefs extending along the slopes, and above them the more massive light-gray limestones of the Carboniferous are well exposed. The beds dip westward in the butte back of Kinneys, conforming to the gradual slope downstream of the quartzite beds of the valley floor. The summit of Smoky Mountain is capped by a flow of basalt, which extends down an eastern spur of the mountains to an elevation 400 feet or more below the summit, clearly proving the unevenness of the surface on which the lava flowed. The rock is very dense, of a dark-gray color, and seems to be liberally sprinkled with minute dots of yellowish olivine and the spots of ocher left by the decomposition of that mineral. It is a normal basalt, very dense, and free from the vesicular cavities so often seen in basaltic lavas. Near the limestone contact the rock is lighter in color, banded, and shows considerable hornblende in acicular crystals and nests.

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[1] See Davis, Relation of coal of Montana to older rocks: Tenth Census, Vol. XV, p. 708, Washington, 1886.

The southern slopes of the mountain are more sparsely wooded and show better exposures than are seen on the Sheep Creek side. An intrusive sheet of porphyry occurs in the Cambrian shales 300 feet below the brown limestone horizon. This sheet of porphyry, which is estimated to be 100 feet thick, forms a prominent bench, and its outcrop is traceable along the smooth slopes for a mile or more. It is largely weathered to a rusty iron-stained mass, which has been prospected at several places along the contact for mineral deposits, but no ore was seen. The rock is a rather coarse-grained rhyolite-porphyry, in which white feldspars and black biotite scales, with occasional small grains of glassy quartz, are seen by the unaided eye. A second intrusive sheet of porphyry is cut by Newland Creek at the base of the slopes, and a dike of darker rock cuts through it and the shales, the contacts of both rocks having been unsuccessfully explored for ores.

VOLCANO VALLEY FAULT.

The head-water valleys of Newland Creek show the Cambrian shales faulted against those of the Belt terrane. The fault is traceable east and west, and is believed to be the extension of the long Volcano Valley fault, by which the Carboniferous and earlier Paleozoic limestones are thrown against the Belt shales. The amount of throw diminishes westward, however. This fault is recognized on the divide between Newland and Sheep creeks, where the Cambrian quartzite forms a small detached wooded ridge rising above the meadows, and the rocks show brecciation and polished slickensided surfaces. The course of the fault was not definitely located west of this, but it is believed to be continued in the faulted beds of Coxcomb Butte. The quartzite exposures just mentioned continue westward, and appear in low reefs dipping at 5° downstream, and flanking the creek meadows a couple of miles below Kinneys.

COXCOMB BUTTE.

The Sheep Creek Valley ends at the base of the dark sharp-crested knob called Coxcomb Butte, sometimes designated as Black Butte. Quartzite is again seen at the southern border of the meadows at the base of this butte, but its age is uncertain, and it may be part of the Belt terrane, though mapped as Cambrian. The bed dips at 5° toward the valley, and the rock is much fractured, iron stained, and jaspery, with green copper stains, which latter led to the digging of prospect pits and the location of a mineral claim. Coxcomb Butte is formed of dense compact quartzite. The beds are on edge and dip at 80° to the east, and are in contact with gray Belt shale whose ready weathering causes the quartzite to stand out in relief. The quartzite is probably faulted, for the upper red shale belt of the Algonkian is wanting, and, moreover, the quartzites show crushing and brecciation. The beds continue northward across the canyon, in whose walls they are seen dipping at 80° to 85° downstream.

SHEEP CREEK COPPER MINES.

Two prospectors who own a hay ranch at the lower end of the valley, Messrs. Weir and Tyler, have located claims on copper-stained seams in the quartzite forming the flanks of the butte. Their claims are located on a secondary ridge alongside of a small drainage cut into the east side of the butte several hundred feet above the meadow.

The Virginia mine is located upon what appears to be a brecciated zone of iron-stained quartzite. The shaft was 70 feet deep in 1894 and a 30-foot drift had been run. Both the surface indications and showing made by workings were extremely poor. There is no evidence of a well-defined vein, and the ore is neither abundant nor rich. The location is probably on the fault line previously mentioned. Unaltered quartzite is exposed on a little ridge to the northwest of the claim. The summit north of the butte shows nearly horizontal beds of pink and gray quartzite, 200 feet thick, dip 1° S.

CANYON OF LOWER SHEEP CREEK.

At the base of Coxcomb Butte the creek enters a canyon cut across ledges of steeply upturned beds of quartzite and indurated sandstone. The beds dip downstream at 80°, and an estimated thickness of 200 feet is seen. In following down the canyon the west side shows quartzite débris, but no exposures appear in the slopes above the wagon road until the red gneisses and schists of the Archean are seen at Moose Creek. The position of the quartzite between Archean gneiss and the Belt shales indicates that it is the Neihart quartzite. The steep dip of the beds and the fact that the flat summit west of the butte shows nearly horizontal beds of pink and gray quartzite capping the gneiss, as well as the finding of similar flat-lying beds of quartzite at the east base of the butte, would indicate a cross fault here at right angles to the main Volcano Valley fault. No direct evidence of this, however, was obtained. Below the mouth of Moose Creek, where an old dam still extends across the main stream, Sheep Creek flows in a narrow and rapidly deepening gorge cut in the Archean gneiss. The slopes of the Archean rocks are rough and covered with fallen timber, but the bedded rocks may be seen high up on the slopes, and several miles down the creek the limestones may be seen dipping at angles of 1° to 3° to the west.

The antiquity of this valley is proved by the occurrence of a flow of dense black basalt. It is first seen a half mile below Moose Creek, forming a cliff 10 to 15 feet in height facing the narrow alluvial flat and making a narrow bench on the hillside. This extends at about the same level to the first creek below Moose, where it is 125 feet thick. It is evident that it fills the ancient valley bottom, but no extensive accumulations of gravel were noted below it, and the creek now flows in a channel cut between the basalt and the slopes to the south, leaving the basalt as a bench with gently sloping top, on the northern slopes far above the present stream. As the under surface of the basalt sheet slopes gently to the east it is clear that the direction of the drainage has been reversed since it occurred.

HEAD WATERS OF SHEEP CREEK.

The valley of Sheep Creek above Wolsey narrows as the thinly bedded Cambrian limestones and conglomerates appear. As already noted in describing Smoky Mountain, the beds dip at a low angle south and the valley is cut along the strike of the beds, so that the higher beds are only encountered as the grade of the valley gradually carries one to higher elevations. Above the mouth of Lamb Creek the direction of the main valley corresponds to the direction of the dip, and as one ascends the stream the descent of the creek is very nearly coincident with the dip of the beds. Near the low pass by which the stage road reaches the head waters of Belt Creek the slope of the valley is, however, a little greater than the dip of the beds, so that the strata seen in

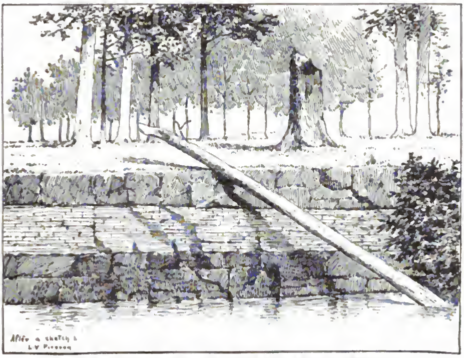

After a sketch by L V Pirsson

FIG. 37.—Minette sheets intruded in limestones, head waters of Sheep Creek.

the steep slopes at the head of the creek are cut through and lower horizons appear lower down near the main valley. This is well shown in the intrusive sheets seen in this locality, which are shown upon the map.

The shale exposures along this part of the creek contain abundant remains of Cambrian invertebrates, from which large collections have been made. The lower shales abound in the wedge-shaped *Hyolithes*, of which some of the beds are almost made up. Nearer the divide the shales contain nodules and thin layers of limestone.

Minette intrusions.—Near the head of Sheep Creek the Cambrian series is intruded by a number of sheets of igneous rock of a totally different type from any of the intrusions observed farther south. A mile or more above an old dam (erected when timbermen were at work in the valley) the soft shales are seen to be cut by a sheet of dark basic-looking rock. The road has been cut across the slope and shows a good exposure of both the intrusive rock and the Logan shales, while near by the creek banks also show excellent exposures. There are several sheets, at least three being noted near the creek. They are from 2 to 4 feet thick, the two lowest separated by an equal thickness of shaly limestone and well exposed in the creek bank (see fig. 37). The latter forms a little cliff 6 to 10 feet high alongside the creek, resting on shale and capped by thinly bedded limestone. Seventy-five feet above, another 5-foot sheet of minette outcrops on the slope, separated by 15 feet of limestone and shale from a still higher 6 to 8 foot sheet. Several still higher sheets probably occur here, as they do in the same strata on the steep slopes east of the Neihart Pass, but they were not located. Though apparently regularly intruded, at least one sheet showed local thickening, and it is believed that the intrusions vary somewhat in horizon, as the unaltered shales are soft and offer little resistance to the breaking through of the magma from one bed to another. In some exposures round bowlder-like masses surrounded by concentric shells of altered material are seen protruding from the face of the exposure and recall the bowlders of granite regions. These bowlders usually show cores of solid, less altered rock, surrounded by shells of material showing more and more alteration.

These rocks are dark colored, and form low, generally rounded outcrops that stand above the shale slopes, the rock being exposed in fresh cuts made in building the wagon road and in low walls along the banks of the creek. They occur as sheets intruded in the shale or, more rarely, as dikes. These intrusive sheets vary from a few inches to 20 feet or more in thickness, and have all produced more or less contact metamorphism of the shales. In the thinner sheets this amounts to merely an induration or hardening of the shale, which becomes slaty, and offers greater resistance to weathering than the unaltered rock. The thicker sheets produce a greater effect upon the rocks in which they are intruded. This is especially noticeable in the thinly bedded, impure limestones, which are indurated to hornstones or to adinole like rocks.

The latter are finely crystalline, banded rocks, of lavender, pale-green, and buff tints, with a conchoidal fracture, which show little nests of pyroxene and cavities lined with brown garnet.

The intrusive rocks themselves are minettes, and are regarded as offshoots of the great stock intrusion of Yogo Peak. They are prevailingly of an olive color, and weather so easily that the rock crumbles to sand very readily. The rocks vary greatly in grain. In the thin sheets and dikes the rock is very dense or fine grained, resembles basalt, resists erosion well, and shows browish weathering extending only an inch or less from the surface into the rock. The thicker sheets consist of a type that is easily recognizable as granular, and that weathers readily to an olive-colored micaceous sand. The finer-grained rocks contain no visible minerals. The coarser forms glitter with the reflections from innumerable little particles of mica, and sometimes show biotite scales or masses a quarter of an inch across, and more rarely as round blebs of olivine. With the lens the specimen is seen to consist of an intimate mixture of biotite and a white component (feldspar) in nearly equal proportions. Calcite seams and round amygdules are also seen in the decomposed rock. The exposures generally show the minette cut by narrow dikelets, 6 inches to 12 feet wide; these are of a light-colored rock which resembles a dense porphyry or aplite, but which petrographic study shows to be a granite-syenite aplite. These little dikes are irregular or crooked in course, and show massive jointing. The most interesting peculiarity of the sheets was observed in the contact portions of one of the intrusions, where the weathered surface was a mass of little round spheres and the fractured surface showed the rocks to be composed of light-gray spheres, smaller than peas, held in an olive matrix. It is a variolitic phase of the rocks above described, which is illustrated in Pl. LXXIII, *B*.

One hundred feet below the divide, on the Sheep Creek side, an intrusive sheet of dense green rock 5 feet thick is seen, forming a low, rounded outcrop near the road. This sheet is intruded in shales and is itself cut by a 3-foot dike of a denser form of the same rock, the dike trending N. 55° E. The petrographic description of these rocks, and of others of the same character from various neighboring localities, is given in the appended paper by Professor Pirsson.

MOUNTAINS NORTH OF SHEEP CREEK.

North of Sheep Creek the main divide of the range is a low line of rounded, heavily timbered summits that rise above the broader parks of Belt Creek and the flat summit levels west of the divide. This mountain tract is formed of beds dipping gently southward or westward near Tenderfoot Creek. It consists of bedded rocks with conformable intrusive sheets of prophyry. Quartzite is the prevailing and most prominent rock here, as it is in the Belt Creek parks.

Williams Mountain.—West of Moose Creek the quartzite is seen resting on Archean gneisses, the present gently southward-sloping surface of the summit of Williams Mountain conforming very closely to the bedding planes of the rocks. North of Wolsey the same structure is found, but the quartzite is here unmistakably Cambrian, as it contains fossil remains and overlies the Belt shales. It covers the summit of the mountain, whose slopes conform closely to the foldings of the rock, but, as the slope is a little steeper than the dip of the beds, the quartzite is cut through, occurring again in the valley at the foot of the mountain, as already mentioned.

Wolsey Mountain.—This name is applied to the mountain north of Sheep Creek. North of Wolsey the lower slopes which rise above the hay meadows are formed of ridges running parallel with the valley. These ridges greatly resemble moraines, but upon close examination are seen to be the result of landslides, due to the slipping of the Flathead quartzite upon the soft Belt shales. The slopes above are thickly wooded, with occasional open parks, up to a level 1,500 feet above the creek. Here the Cambrian quartzite is seen dipping south at 5°. Where the quartzite forms the surface the woods become more open, and spruces and firs occur, with frequent upland meadows which extend up to an altitude of 2,350 feet above the creek. Here an abrupt cliff marks the front of a basalt cap that forms the summit of the mountain. The total thickness of basalt is about 75 feet. The rock varies somewhat in character, ranging from a dense, compact, black basalt to a slaggy or brecciated, vesicular form, but presents no petrographic features of special interest. The main divide is covered by the usual heavy forest of lodgepole pine, and shows long talus heapings of prophyry, the débris from a sheet of rhyolite-porphyry which extends from Porphyry Peak to the head of Tillinghast Creek.

Porphyry Peak.—This is the summit west of the pass at the head of Sheep Creek. It consists of shales with several intruded sheets of porphyry, one of which is now exposed and forms its summit. These sheets are seldom well exposed, for the rock breaks into small débris, which is usually much altered. In the eastern spur of the peak, running down to the pass, two sheets were identified, but so widespread is the débris that others, if present, would scarcely be recognized in the dense woods that cover the slopes. A minette sheet was found 250 feet below the summit, and another sheet is intruded in the shales beneath the porphyry cap of the summit, whose lower surface is cut by the minette. The rock is similar to that exposed along Sheep Creek at the east base of the peak.

JUDITH REGION.

PLATEAUS OF THE JUDITH.

South of Yogo Creek the main summits and eastern slope of the Little Belt Range are a plateau country that is deeply trenched by the three forks of the Judith River. The summit has an eastward inclination, which is slight on the main watershed but pronounced on the extension of the plateau eastward into the interstream areas. These summits are margined by escarpments that rise above the steep slopes of sharply V-shaped valleys. The mountain top is a park region, showing extensive areas of open grass land with clumps of spruce and fir and groves of pine. The streams head in deep amphitheaters cut in the nearly horizontal rocks of the summit, and are fed by perennial springs and by the melting of the great snow banks which gather in these amphitheaters during the storms of the long winter season. The three streams—Yogo Creek, Middle Fork, and South Fork, which uniting form the Judith River, just east of the range—all have sharply cut head-water courses leading into an open mountain valley. Below these valleys the streams flow through deep and narrow canyons whose pinnacled walls of white limestone are extremely picturesque.

The structure of this part of the range is simple. It is formed of the stratified rocks, whose beds are nearly horizontal on the main divide, the dip being but 5° eastward, while on Prospect Ridge and Lost Fork Plateau and in the walls of the lower canyons the dip is from 10° to 15°. As a consequence of this easterly dip the summit escarpments and creek canyons show these beds in orderly sequence, and the different formations exhibit their peculiarities of weathering and of color in remarkably well-exposed sections. The summit areas, on the contrary, show few natural sections, for the surface slopes eastward and very nearly coincides with the dip of the strata, so that large areas are often covered by a single bed. As a consequence of the gradient of the stream channels, steep near the head and low farther east, the three main valleys cut deepest into the sedimentary series 6 to 10 miles east of the divide, and the uplift of the range being greater to the south, the South Fork exposes the oldest beds.

In this southern part of the range there are no igneous rocks, but they appear in the form of sheets and dikes about the head waters of the Middle Fork, and become the most prominent and important elements of both structure and scenery north of Yogo Creek.

SOUTH FORK.

The South Fork exposes the only area of the Belt rocks found on the east side of the range. The rocks are the usual gray shales, which are deeply trenched by the streams. The beds do not dip directly east, for the strata dip away from the arch forming the eastern end of the range. The Belt shales

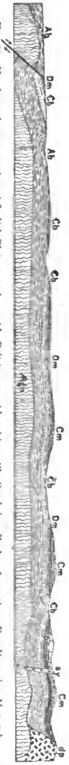


FIG. 38.—North-south cross section of Judith Plateau region. Ab, Belt terrace, Algonkian; Cb, Cambrian, Barker formation; Dm, Devonian, Monarch formation; Cm, Carboniferous, Madison limestone; sy, syenite; dp, diorite-porphyry.

are overlain by the reddish sandstones and quartzites of Cambrian age—the Flathead quartzite, which is a very durable rock and forms extensive areas of densely wooded plateaus sloping northwestward. North of the stream these quartzites pass beneath the surface, and the parks of the region are underlain by the soft micaceous shales and thinly bedded limestones. The absence of igneous rocks coincides with the reported lack of mineral discoveries in this region. The climate here is far too rigorous for agriculture, though the parks afford summer pasturage for large herds of cattle. The lower canyon is traversed by a wagon road from Hoover to the forks of the river, the canyon being wider and the bottom less rugged than that of the northern forks.

MIDDLE FORK.

The Middle Fork is the largest of the three branches of the Judith heading in the range. It drains a large part of the main summit region south of Yogo Peak, and one of its tributaries drains the plateau country to the south, generally known as Lost Fork Plateau. The lower canyon, below Lost Fork, is a narrow and tortuous gorge 6 miles long, in which the trail has to follow the creek channel for much of the way. Above Lost Fork the valley widens, and the creek is bordered by bench-land parks, on which hay has been cut and cattle have been pastured for several years past. The small head-water streams have received the name of prospectors who have explored them or found mineral deposits upon their borders. Many claims have been located and rich samples of gold, silver, and copper ores brought to Neihart at various times, but the inaccessibility of the region has deterred development, and no mining has been done nor any ore shipped during the ten or more years in which the various discoveries have been known.

A rude wagon road was built many years ago from the old Neihart stage road on O'Brien Creek to the summit of the range and down King Creek to an arrastre erected to treat oxidized ores found near by. The easiest outlet for the locality is down the stream to Utica, a longer but an easier route for a wagon road.

The summit of the range at the head of Weatherwax Creek is formed by a bed of massive limestone containing Cambrian fossils. This bed overlies the shaly beds in which the head-water valleys are all cut, and which are also exposed on the slopes west of the summit at the head of Sheep Creek. At the head of Weatherwax Creek the main divide is cut down through this bed, but it appears southward at the base of the limestone ledges which form the flat 8,000-foot summit rising above the divide at the head of Collins Creek. These higher rocks are also seen in a knob on the ridge between King and Harrison creeks, and in the main summit northward, where the Cambrian limestone (Gallatin group) is seen overlain by a few feet of greenish shale and then by red earthy shales, capped in turn by pinkish or buff-colored shaly limestones that overlie the low masonry-like courses of black or dark-brown limestone of the Monarch formation shown in Pl. XLII, *A*. The beds are from 3 to 5 feet thick, and consist of a distinctly granular limestone with a peculiarly etched surface, and often pitted by cavities where calcite geodes or coral masses have weathered out. The section from the quartzite of Sheep Creek to the base of the brown limestone series shows a thickness of 1,000 feet of Cambrian strata. In the ridge north of King Creek the brown Monarch limestones are estimated to be 140 feet thick. The beds dip eastward at a low angle and are covered by dark-blue shaly limestones which contain an abundance of fossil remains that show in relief upon the buff-colored weathered surfaces of the rock. These shaly limestones break readily into shaly débris, and are seldom seen in massive exposures.

Igneous rocks.—The upper valleys of Middle Fork show many intrusions of igneous rock. They occur chiefly in the soft, easily penetrated Cambrian shales, more rarely in the shaly beds of higher horizons. Both dikes and sheets occur, but the former are less common and do not form so important a feature of scenery and structure as the sheets. These intruded sheets are in some respects the most conspicuous rocks of the region, their resistance to erosion leaving them in relief as ledges banding the mountain sides. Their débris piles are conspicuous, and they are especially noticeable as crescent-shaped benches on the spurs or lateral ridges seen along the valley sides. The rocks are of two types—the rhyolite- or trachyte-porphyries, the light-colored rocks, forming the thicker, more conspicuous intrusions; and the dark-colored rocks, which are mostly minettes or closely allied rocks, and decompose readily, and though quite as common in occurrence as the former, are not recognizable at a distance, as they seldom form conspicuous exposures.

The light-colored rocks are feldspathic porphyries of a pinkish tone on weathered surfaces, or straw colored on fresh fracture. The tints are due to the hydrated iron oxides disseminated through the rocks and resulting from the decay of some iron-bearing mineral. All of the rocks have been greatly altered, and in part mineralized, so that the contacts have been more or less prospected. The basic rocks have baked and altered the adjacent shales; the feldspathic porphyries have produced little if any alteration of the rocks in contact with them.

The ridge previously mentioned, lying between King and Harrison creeks, is crowned by a mass of feldspar-porphyry, forming a sharp knob or summit. This porphyry is part of an intrusive sheet recognizable also in the summit to the north. It is estimated to be 150 feet thick, and as it lies upon the strata its lower surface, at least, conforms to them in dip. It extends a mile or more eastward down the ridge. The rock is believed to be a remnant of an extensive intruded sheet uncovered by erosion, which extends far down the ridge to the east. It has produced almost no metamorphism of the underlying shaly limestones, though a prospect pit at the contact shows a little ore, and the under contact is more or less mineralized. In the outcrop the rock is shattered and breaks into platy débris. It is light colored, with a reddish tinge on weathered surfaces, but of a light-gray color when unaltered. The dense, compact groundmass is dotted with occasional opaque white spots of feldspar of varying size up to one-half inch in diameter, with a sprinkling of small flakes of rather dull biotite-mica. The rock is altered, though less so than most of the igneous rocks of the neighborhood, and is probably to be classed as a quartz-syenite-porphyry (quartz-mica-syenite), as noted in the petrographic chapters.

From the summit of the ridge a comprehensive view is obtained of the neighboring country. It is at once noticed that the benches and dark-colored débris piles seen on the spurs or ridges between the various streams near by, all occur at about the same level. This suggested what subsequent visits proved to be true—that a single sheet of igneous rock forms all the exposures seen at the same horizon; and as the principal exposures are lower, both in elevation and in stratigraphic sequence, than the Jefferson limestones, the sheet forming them is intruded near the top of the Cambrian shales. This sheet is probably the one encountered in the bottom of Harrison Creek north of the King Creek summit, at 1,250 feet below the top, and 100 feet above the forks of King and Weatherwax creeks. At the latter locality the sheet is estimated to be but 15 feet thick, but it forms a ledge traceable around the slope and up Harrison Creek. One hundred feet below this porphyry sheet an intrusive sheet of minette cuts the shales, and at a still lower elevation another porphyry sheet 30 feet thick forms low cliffs alongside of Weatherwax Creek, and as the valley deepens is seen in bold cliffs and benches on the spurs. The minette sheet at the mouth of King Creek is seen for 3 miles as a prominent ledge on the grassy open slopes northeast of the creek. It forms a little level at the mouth of King Creek, where it is well exposed, and is seen to have produced considerable alteration of the shales and thinly bedded limestones in which it is intruded. The exposure is nearly horizontal, as the course of the valley is along the strike of the strata in which the sheet is intruded. This minette sheet was not followed beyond Harrison Creek, but it extends up that creek, and probably occurs on the spur between it and Cleveland Creek.

A dike was found cutting the shaly limestones at the head of King Creek, which probably also cuts the porphyry forming the summit north of that stream. It is seen cutting the shales on the steep slopes descending the channel of Harrison Creek, where it is 20 feet wide, has a dip to the west, and has baked and altered the shale for several feet from the contact. The trend is northeast, but as the rock weathers readily it is not recognizable northward, where the ridges are capped with the Carboniferous limestones. The rock is altered to an olive or brown, sandy material, but is readily identified as a minette. It shows the peculiar warty surface and variolitic structure on contact surfaces and also on joint (shrinkage?) planes noted in the Sheep Creek rocks. A second dike of minette, showing at the contact the variolitic faces noted in the sheets of Sheep Creek, is seen near the mouth of a tributary of Harrison Creek below the dike just noted. The trend is N. 20° E. The rock is an augite-minette. It does not at all resemble the other minettes, as it is a dense, very dark gray, almost black, rock, whose groundmass glitters with reflections from minute mica scales. The only mineral recognizable by the eye is brown biotite.

On the north side of Harrison Creek the wash of the soft shale covers the slope, so that the underlying rock in place is seldom seen. A sheet of minette forms a bench 600 feet above the creek, and 200 feet above this rock a 25-foot sheet of hornblende-porphyry is found whose position and petrographic character correspond to those of the sheet found on King Creek. It is probably the northern extension of that sheet, though the interval between it and the minette sheet is 100 feet greater than at the mouth of King Creek. If this be true, it shows that the sheets vary somewhat in the horizon of intrusion at different localities, as would be expected in these soft shales. The higher slopes north of Harrison show the same intrusive sheet that is found capping the summit between King and Harrison creeks.

The valley of the Middle Fork below Harrison Creek broadens out, and for several miles shows a beautiful open, meadow benchland at the base of the densely wooded southern slopes. These slopes show no exposures, though the porphyry sheet already mentioned forms a recognizable bench and black talus slope on all the spurs. The slopes north of the creek are scantily wooded or open, thin soiled, and show good exposures. At the mouth of Harrison Creek the stream cuts a sheet of greenish basic rock, too altered for absolute determination, but probably minette. At Cleveland Creek, where a cattle ranch has been established, there is a mass of basic rock intimately associated with an intrusion of light-colored porphyry that forms a broad bench north of the creek and is exposed in columnar cliffs extending down the stream for several miles. The porphyry is probably laccolithic in form, for the Cambrian beds north of the creek dip away from it at an angle of 25°, though the summit escarpments on either side show the usual easterly dipping beds. The general easterly dip of the Devonian and Carboniferous limestones is not altered, as the ledges may be seen far above the valley dipping gently eastward.

The rocks exposed at the mouth of Cleveland Creek are the lowest beds seen, as below here the prevailing easterly dip just noted brings successively higher beds to the valley bottom. Two intrusive sheets were noted in the shales east of here, the rocks belonging to the minette group. About 2 miles above the mouth of Lost Fork the massive limestones, which dip downstream at a low angle, reach the creek bottom, and the valley narrows and soon becomes a deep canyon. The cliffs and creek banks show unusually good exposures of the softer beds of the sedimentary section. The brown Jefferson limestones are here seen to be overlain by shaly red limestones, often spotted with green. These are overlain by the thinly bedded limestones carrying Carboniferous fossils and forming the base of a series of bedded limestones whose cliffs are often orange colored. From these exposures eastward the creek canyon is cut in Carboniferous beds, and no igneous rocks are seen until the broad basin of the Judith is reached, in which the sapphire mines occur.

Prospect Ridge is the broad block of limestone between Yogo Creek and Middle Fork. While the block shows the general easterly dip already noted, there is some local warping or buckling. The summit shows a gentle anticlinal arch, the beds dipping at 3° to 5° toward the valleys on either side. This inclination is more marked opposite Yogo, where it amounts to 10°.

CHAPTER IV.

DESCRIPTIVE GEOLOGY OF THE YOGO DISTRICT, BIG BALDY MOUNTAIN, WOLF BUTTE, AND TAYLOR PEAK.

YOGO DISTRICT.

The mountainous tract included between Yogo Creek on the south and Dry Wolf Creek Valley (Big Park) on the northwest is conveniently described as the Yogo district. It includes several areas where prospecting and mining operations have been more or less vigorously carried on at various periods in the past, the best known being those of Yogo proper, the Yogo sapphire field, Lion Gulch, and Running Wolf Creek. The last named is the only one from which ore has been shipped. The region thus delimited presents a far more irregular surface and a more complex geologic structure than that so far described. The highest point, Yogo Peak, is the westernmost summit of a somewhat irregular ridge extending northeastward and forming the main water parting of the district. A northern spur of this ridge ends in Steamboat Mountain, as the summit between Dry Wolf and Running Wolf creeks is locally called. The main divide continued eastward ends in two separate elevations, the northern of which is Woodhurst Mountain; the southern is, for lack of a name, here called Sage Creek Mountain. A fourth detached mountain, lying between Sage and Yogo creeks, is here called Ricard Peak.

Yogo Peak and the ridge east of it are formed of a mass of igneous rock breaking through folded sedimentary rocks. The outlying mountain masses mentioned above are laccoliths—that is, great blister-like elevations of the strata lifted up by intrusions of igneous rocks. The igneous rocks determine, therefore, the main features of the topography of the region, as they do the geologic structure.

The ridge of which Yogo Peak is the western end is formed of a continuous body of massive igneous rock extending from Yogo Peak to the eastern foothills of Woodhurst Mountain, a distance of 13 miles. This long and relatively narrow body of massive rock is an intrusion which fills an irregular fracture in upturned sedimentary rocks. The western end of this fracture, at Yogo Peak, appears to be a chimney or core, the center of disturbance at the time of igneous activity, from which the dikes seen for many miles about seem to radiate, and which for a distance of 10 miles or more is encircled by intrusive sheets in the softer, more easily penetrated formations of the sedimentary series.

The mass as a whole shows an apparently continuous single body of rock that presents a remarkable gradation of types at the western end of the fracture. Owing to the importance of the mass and the deductions derived from the study of its rocks, the field observations are given in considerable detail.

YOGO PEAK.

Location.—Yogo Peak is from many points of view the most conspicuous elevation of the Little Belt Range. Although not snow capped, it projects above the timber line, and its somber crown of crags, formed of massive igneous rock, is in sharp contrast to the rounded summits and level plateaus adjacent. (Pl. XLVII, *B*.) It is situated 8 miles east of Neihart and on the high divide between the waters of Belt Creek and the Judith River, and reaches an elevation of 8,625 feet above tide water. The adjacent streams have cut deeply through the horizontal sedimentary rocks, and the broad valley bottom of Dry Wolf Creek on the north and the placer bars of Yogo on the south are 3,000 feet below the crags of the mountain summit. It is readily accessible, as a well-traveled trail, which is the route from Neihart to Judith Basin, crosses its summit.

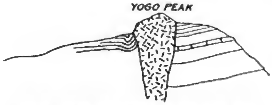


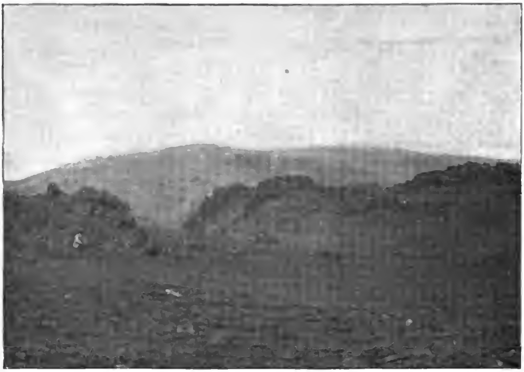
FIG. 39.—North-south section through Yogo Peak.

Character of rocks.—The peak is composed of coarse-grained massive rocks, showing a progressive gradation from very dark-colored augitic forms at the western contact to lighter-colored, more feldspathic, finer-grained rocks forming the eastern part of the peak. These rocks are fully described in the petrographic chapters, so that only the more general facts will be given here.

WESTERN KNOB.

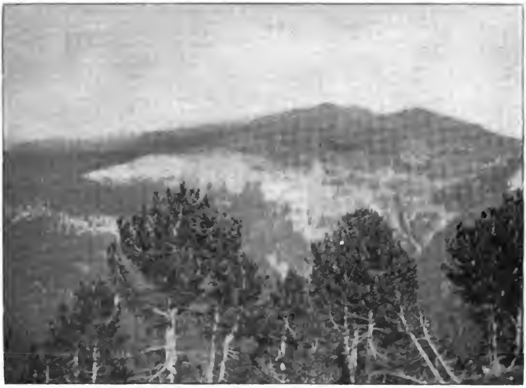
A grassy depression or sag, which affords an easy descent for the trail to the head of Yogo Creek, divides the summit of the peak into eastern and western parts. The western summit has an irregular surface, on which ruin-like masses and crags, with curiously shaped monoliths and bowlders, rise above the small grassy plats lying between them. (Pl. XLVII, *A*.) The rock forming these crags has a very massive jointing, is exceedingly tough, and breaks with great difficulty. On the western slopes of the peak the rock disintegrates readily on weathering and forms a coarse sand, the rock being seen only in little gullies washed in the slope.

Shonkinite.—The rock appears at first sight to consist principally of coarse biotite. It is very coarse grained, and in the exposure is so



A. SUMMIT OF BIG BALDY MOUNTAIN, SEEN FROM THE ALPINE MEADOW ON TOP OF YOGO PEAK.

Shonkinite bowlders in foreground. Note the smooth, rounded contour of Big Baldy Mountain, which is the slightly eroded surface of the bysmalith.



B. YOGO PEAK, SEEN FROM THE BELT CREEK DIVIDE.

Showing crown of bowlder and "hoodoo" crags of shonkinite.

loosely textured that good specimens are obtained with difficulty. This type is the most basic one found, and lies nearest the west contact. It consists of augite and biotite, which far exceed the feldspar in amount. The glistening bronzy plates of biotite are the most conspicuous minerals, though the augite is present in greater quantities. The rock also contains small masses of glassy olivine. The feldspar is almost wholly orthoclase, and the rock is a shonkinite—that is, a coarse-grained rock composed of augite and biotite with a smaller amount of orthoclase.

Upon the summit the rocks composing the crags and monoliths are denser in grain than the type just noted. The exposures show, however, a considerable variation in grain, the coarse and fine grained forms being mixed as if stirred together while still pasty. The denser rocks form the exposed masses; the coarser varieties weather down and form the grassy interspaces. All gradations may be found between very fine and very coarse grained types. The prevailing rock seen in the massive exposures, though less coarse than that of the western slope of the peak, is yet a coarse-grained rock of a very dark-gray color. The dark-colored minerals are in excess, and the rock glistens with the light reflected from the numerous plates of biotite, and is dotted with round, rusty-brown spots. With the lens an abundance of small augites are also seen in the feldspars. The feldspar is chiefly orthoclase. The microscopic study of this rock shows that it is also a typical shonkinite, but contains less of the dark-colored minerals than the coarser-grained form nearer the contact.

Dikes cutting shonkinite.—The rocks of the western part of the summit are cut by a number of tiny dikes which vary from a fraction of an inch to several inches in width (fig. 73). The dike rock is of uniform character, very light gray or pink in color, and is recognizable as granular to the eye. The finer grain of the rock causes it to weather in relief upon exposed surfaces. The widest dike cutting the shonkinite is a rather coarse-grained syenite, containing inclusions of the shonkinite. The smaller ores are but little finer in grain. In one instance a 2-inch dike showed a well-marked darker colored, much denser contact band 1 mm. in width, but usually no such contact band is recognizable in the hand specimen. Dikes of a syenite-porphyry and of a dark-green augite-minette probably cut this rock, for their débris was found near the saddle separating the two summits, but the rocks could not be found in place.

MIDDLE KNOB.

In crossing the summit eastward to the saddle the rocks show a gradual change in character, becoming lighter colored and more feldspathic, and have a general mottled appearance. The weathering is less massive, and there is a tendency to break into thick slabs and rectangular blocks, which is well illustrated in the sharp little knob on the south side just east of the trail. The rock is very clearly finer grained than the shonkinite, but is composed of the same minerals, though feldspathic constituents are more abundant, giving it a decided gray color, of a greenish tint, on fresh fracture. As is shown in the petrographic description, the feldspar consists of nearly equal amounts of orthoclase and plagioclase (oligoclase andesine). It is a typical monzonite, and is quite clearly seen to grade into the shonkinite.

EASTERN KNOB.

The eastern summit of Yogo Peak has a rounded form and is covered by the platy débris into which the rock weathers. The rock mass composing it and the high eastern shoulder of the mountain possesses a platy parting which causes it to split readily and to form piles of débris and talus slopes, above which project the low and much-jointed exposures of the rock in place. The joint blocks are short, stout rhomboids or heavy plates a foot or so long. They are very hard and tough, ring sonorously under the hammer, and are broken with difficulty, the rock being unaltered and fresh. These characters prevail for the entire Yogo Peak mass. On a freshly fractured surface the rock appears evenly granular, of moderately fine grain, and is compact in character and with few miarolitic cavities. The color is a medium gray with a strong pinkish tone. The rock is clearly a feldspathic one, and of syenite aspect. Examined with the lens, it is seen to be chiefly composed of light-colored feldspar, dotted with small, dark, formless spots of green pyroxene or hornblende. The rock is very unlike that of the types previously described, but the monzonite forms a transition phase between this rock and the shonkinite. No actual gradation of the monzonite into this syenite was observed in the field, a gentle grassy slope scattered with black bowlders extending up to the base of the platy talus slide. The plates seen on the summit show partly rounded or subangular inclusions of a coarser-grained augitic rock, like the monzonite and shonkinite of the western summit of the peak. The rock is also cut by little dikelets, from an inch to several inches in width, of a lighter-colored, finer-grained, more feldspathic syenite, regarded as an aplitic form of the rock. This syenite continues eastward without change in character, to the steep slopes that form the eastern shoulder of the peak, there being an abrupt descent of 600 feet to the broad and open-parked summit of the ridge. That the syenite extends to the southern contact is shown in the walls of the little amphitheater cut in its southeast side, the contact with the sedimentary rocks being seen on the shores of the lakelets at the bottom of this amphitheater.

EASTERN SHOULDER.

The platy débris covering the eastern shoulder of Yogo Peak and the steep slopes that define it from the broad and wooded summit of the ridge to the east, shows a very gradual change in the appearance of the syenite, from the evenly granular rock of the peak to a decidedly porphyritic form constituting the talus of the eastern slope. The latter may be regarded as a transition form to the lighter-colored, more feldspathic syenite-porphyry which is seen immediately east of the peak. The rock still has a granular character, and contains some hornblende and augite, but its distinctive feature is the presence of large square feldspar crystals. These resist weathering better than the groundmass and stand out in relief upon the rock surface, giving it a slight resemblance to a conglomerate. Where the rock has weathered down, these feldspars form a sandy gravel. This rock contains microscopic quartz grains and may be classed as an amphibole-granite-porphyry or a quartz-syenite.

ELK RIDGE SUMMIT.

The slightly accidented surface of the ridge, designated Elk Ridge, which extends eastward from Yogo Peak to the cliffs at the head of Lion and Elk gulches shows few exposures. A sharp point rises above the general level at the north edge of the summit. The slopes of this eminence consist of platy brown débris, while its top shows massive exposures of the rock. Several varieties occur here, presenting gradations similar to those noted at Yogo Peak. The prevailing form is a monzonite associated with a lighter-colored granite-syenite. Both these rocks are cut by a dike of dark basic rock, running toward Yogo Peak, but having a dip of 50° NW. This dike rock shows porphyritic crystals of augite and olivine in a dense black groundmass, and is found to be an augite-minette. In the transverse ridge or summit, crossing the ridge near the head of Lion Creek, the rocks are again well exposed. They are no longer porphyritic, but are coarse and even grained syenite, rather dark in color, which grades into shonkinite in the escarpments on either side, the rocks being contact forms of the mass. The shonkinite also forms a narrow, dike-like mass which extends eastward and makes the divide between Lion Gulch and the waters of Yogo Creek. A contact form of this rock is an augite-minette.

DIKES CONNECTING YOGO AND WOODHURST STOCKS.

At the locality last noted, which lies nearly north of the Yogo settlement, the intrusion is no longer a wide one, but splits up into three narrow, dike-like masses, only one of which continues eastward and expands into the broad masses seen at Sheep Mountain and in the chain of hills north of Bear Park and Sage Creek. This intrusion is but a few yards wide where it crosses the saddle back of Schoppe Mountain, whence it runs diagonally across the basin of Skunk Creek, where it is not over 200 yards wide, and is seen cutting the limestones in the walls of Sheep Mountain. In the saddle between Sheep and Bandbox mountains a similar dike-like mass runs transversely across the ridge, and shows a mass of shonkinite, flanked by porphyry on the north, the contact being abrupt and without gradation. The relations of this mass to the main intrusion were not determined.

STRUCTURAL RELATIONS.

The intrusion is a stock or intrusive mass that occupies an irregular fracture in the sedimentary rocks and has an abrupt, nearly vertical, contact. This is clearly shown at a number of localities where the contact is well exposed, though in general the actual plane of contact is hidden by débris or soil and is not seen. It is well exposed on the borders of the ponds seen in the floor of the amphitheater cut into the northeast side of Yogo Peak and also in similar amphitheaters southwest of the peak, where the plane of contact is vertical. Upon the west and southern sides of Yogo Peak the strata are locally undisturbed by the intrusion, but elsewhere the sedimentary rocks maintain the same general attitude as those of the surrounding undisturbed parts of the range. Thus, upon the northern spurs of Yogo Peak the limestones are tilted, the dip being 10° S. toward Yogo Peak, as seen in the photographs reproduced on Pl. XLVII, *B*. The beds make benched slopes with steep cliffs and level benches sloping gently inward toward the peak. The beds here exposed can be traced continuously eastward in persistent cliffs and ledges, gradually running down the slopes below as far as Lion Creek, where the beds which form the creek bottom are the same as those seen high up on the northern shoulder of Yogo Peak. West of Yogo Peak the ridge connecting the peak with the western summits shows slightly tilted limestones, but at the base of the peak, at the immediate contact with the massive rocks, the strata are steeply upturned. These beds and those seen south of the peak appear to be broken and uptilted blocks produced by a punching up of the massive rock in opening its conduit. The rocks are so highly altered that it was impossible to determine their age. These upturned sedimentary rocks are well exposed on the south side of the peak, and on the spur which runs down into Yogo Creek that is traversed by the trail. The beds dip away from the intrusion, the angle of dip being 60° to 65° south of the eastern summit of Yogo Peak. The lateral spurs extending south from the peak toward Yogo Creek show crumpled and warped beds, which, however, pass gradually into less-disturbed strata in a very short distance from the contact. These disturbed beds appear to be abruptly uptilted by the intrusion. It is not a laccolithic uplift, and for the most part the uptilted strata are fractured and uplifted blocks—the broken-off ends of the beds through which the intrusion has occurred.

CONTACT METAMORPHISM.

The sedimentary rocks are highly altered at and near the contact with the igneous rocks. This alteration is greatest, of course, near the contact, and becomes less and less marked as the distance from it increases. In no case is it intense, and the zone of noticeable metamorphism is rarely over a few hundred yards wide and generally only a few yards across. Where the metamorphism is most marked the purer limestones form coarsely granular marbles. The less-pure limestones are aggregates of calcite, garnet, epidote, and other characteristic contact minerals. Farther away the heat of the intrusion has produced an induration of the beds and developed joints and strains in the rock, which cause it to break into fine angular débris on weathering. This contact metamorphism is most marked about Yogo Peak, and eastward as far as Lion Creek and Sheep Mountain. It is much less east of the places where the intrusion is a porphyry and not a coarsely granular rock. In general, it has been found that the more basic the rock the greater is the effect of contact metamorphism.

The altered rocks are mostly somewhat loosely textured and crystalline, so that they weather more readily than either the massive igneous rock or the unaltered sedimentary ones. The prominence of the igneous rock, forming as it does so high a peak and mountain ridge, is probably largely due to this fact. The slopes of Yogo Peak rise steeply on all sides above the surrounding area of sedimentary rocks. From Yogo Peak eastward to Lion Creek and a little beyond, the igneous area has a relatively flat summit, bordered by cliffs of massive rock that rise as an escarpment above the contact zone of altered sediments. This steep slope of Yogo Peak and this escarpment are no doubt due in part to the resistant characters of the syenite, but more directly, perhaps, to the nature of the altered sediments, whose coarsely crystalline texture yields readily to the processes of weathering, crumbling, and disintegrating. This material is removed rapidly by wind and water, so as to leave the igneous rock in relief, and the cliffs seen are probably the denuded and exposed contact planes of the intrusion. This contact zone is often marked by seams and fissures of iron-stained or clayey material and by ore deposits. These ore deposits have been prospected at frequent intervals, and for many miles the contact can be traced by them. Rich specimens of ore have been found, but thus far no productive ore bodies have been discovered. At most of the localities about the contact the altered rocks were originally limestones, but in the branches of Wolf Creek, west of Lion Gulch, there is a large amount of débris derived from the eruptive contact. This débris consists of hornstone and adinole—the dense rocks produced by the baking and alteration of the Cambrian shales.

GROUP OF ENCIRCLING SHEETS ABOUT THE YOGO STOCK.

Yogo Peak is the center from which a great number of sheets of igneous rock were intruded into the sedimentary rocks of the range. These sheets, which by denudation are now exposed, encircle the peak for a radius of at least 10 miles, and form conspicuous elements of the scenery and mountain structure, while if the laccoliths be regarded as enormously thickened sheets, the highest and largest mountains of the range are formed by them. The sheets occur chiefly in the soft and easily intruded Cambrian shales, where they are very abundant, but they are also found at higher shaly horizons which are easily intruded.

These sheets are formed of various rocks which exhibit a considerable diversity of texture and of mineral composition, but may be grouped as trachytic or rhyolitic rocks, and as lamprophyres or basic rocks, chiefly minettes. The former are the common porphyries of the region. They are hard rocks, which resist weathering better than the soft shaly rocks in which they are intruded. They form escarpments or mountain slopes and spurs, very often fronting benches determined by the occurrence of the sheet, and having broad talus slopes at the base. These sheets form the most prominent feature of the country about the head waters of Belt Creek, the Middle Fork of the Judith, and Sheep Creek, and their occurrence is described in the detailed description given of these localities. The basic sheets are probably quite as numerous as those of the acidic rock; but they weather readily, generally forming a slightly coherent brown sand, and are therefore seldom recognizable on the mountain spurs and slopes; thus those which have been mapped and visited probably represent but a small part of the total number. These sheets generally produce considerable metamorphism of the rocks near their contact. The two classes of rocks forming the intrusive sheets exhibit various gradations, but may be classed as porphyries and as minette and analcite-basalt. They represent in another form the same rock magma which at Yogo Peak has consolidated as shonkinite and syenite. In the sheets the rapid cooling of the thinner mass has resulted in different texture and somewhat different mineral composition. The petrographic features of these rocks are given in detail in the accompanying paper by Professor Pirsson, but attention may here be called to their leading characteristics.

While the connection of the various intrusive sheets observed in the range for many miles about Yogo Peak can not be directly established, there is strong evidence of it. Such sheets are abundant in the spurs of Yogo Peak and vicinity, and on the north side of the ridge they can be traced to within short distances of the massive rock. Though the actual physical connection was in no case established, there seems no reason to doubt their origin from that center.

The lateral spurs of Yogo Peak contain at least three intrusive sheets in the upper part of the mountain slopes, showing as columnar cliffs where deeply trenched by streams, and forming pronounced benches indenting the crests of the spurs, with dark talus slides. The west wall of the second gulch southwest of Lion presents cliffs of well-bedded white limestones dipping 10° NE., while the opposite eastern walls of the gulch show the brown Monarch limestones at the base of the bluff, capped by an intrusive sheet which forms the top of lesser ridges, but on the higher ones is overlain by the white Carboniferous limestones. This same sheet is continued eastward, and may be seen in Lion Gulch, near the Gold Dust mine. It is a much altered syenite-porphyry. In the lower slopes several sheets are seen cutting the Cambrian shales, and as these occur at the same horizons and show the same intervals between them, and consist of the same rocks, as those found in the spur of Big Baldy Mountain north of Big Park, it is evident they once extended across the valley.

West of Yogo Peak the ridge connecting it with the main divide of the range is largely covered by the débris of an intrusive sheet of porphyry. The underlying rocks have a gentle dip. The Cambrian shales and shaly limestones are here, as elsewhere about Yogo Peak, intruded by sheets of porphyry, showing as ledges banding the slopes and as caps to the buttes which rise above the general summits. In the upturned strata seen at the contact with the main stock, three sheets, each from 5 to 10 feet thick, are intruded in the limestones. The rocks are very greatly altered, but are recognizable as fine-grained syenites or syenite-porphyries. A sheet 100 feet thick, forming the amphitheater walls southwest of the peak, appears to be continuous with the sheet seen on the ridge to the west running across the ridge to the head of Wolf Creek. The rock is a syenite precisely like that noted at the shaft house on the west contact of Yogo Peak.

South of the peak the open limestone summit at the head of Yogo Creek shows the usual prospect pits found in the contact zone. Two intrusive sheets that occur here in the upturned limestone are slightly faulted. The spur leading down into Yogo Creek from the last-named locality shows upturned strata in which two intrusive sheets were seen. To the east the lateral spurs of Yogo Peak show intrusive sheets whose darker weathering is in strong contrast to the white limestones. In the spur west of the Yogo settlement an isolated remnant of a sheet forms a turret, capping white limestones, and capped in turn by a smaller mass of white marble. The thickly bedded limestones of the Carboniferous do not split apart readily along their bedding planes, and it is rare to find intrusive sheets in these rocks. This probably accounts for the general observance of intrusive sheets in the rocks adjacent to the eastern extension of the Yogo Peak core. The sheets of Wolf Creek Park (Big Park) are described under that heading (p. 341).

FRINGING DIKES.

General relations.—The dikes which cut the sedimentary rocks for a radius of 12 miles about Yogo Peak are believed to have their origin in that locus of igneous activity, as in general they radiate from Yogo Peak as a center. They vary greatly in appearance and also in mineral composition, but are nearly all basic rocks, trachytic or rhyolitic rocks being very rare in this group of dikes. They are generally dark colored, and when intruded in limestones or light feldspathic syenitic rocks are quite conspicuous. More commonly, however, they yield readily to weathering and are barely recognizable even close at hand. The minette dikes of Sheep Creek and of King and Harrison creeks have already been described. The granite-porphyry of Big Baldy Mountain is cut by analcite-basalts, which are seen on the summit and are prominent in the amphitheater walls. The shales and intruded sheets at the base of this mountain are cut by two dikes of minette. Another group is seen exposed on the saddle at the head of Running Wolf Creek, in the valley of that creek, on spurs of Steamboat Mountain, and on the ridge south of the creek. It is probable that but a small part of the total number have been seen in mapping the geology. These dikes cut sheets of feldspathic porphyry at a number of places, and hence are certainly later. They are found much farther from the center than the acidic sheets, but no farther than sheets of similar basic rocks. The most interesting of these dikes are probably those of Bandbox Mountain and the dike from which the Yogo sapphires are obtained.

Bandbox Mountain dikes.—Bandbox Mountain is the name given to a flat-topped elevation whose encircling cliffs and girdle of limestones have doubtless suggested the name. The mountain consists of gently tilted Carboniferous limestone, of which good exposures occur in the summit cliffs. The rocks are shaly, thin-bedded or flaggy, dark-gray limestones, and carry abundant fossils of Carboniferous types. The summit of the mountain is smooth, open, and grassy, and conforms in shape to the bedding planes of the limestone, dipping N. 13°, magnetic. The massive bed of limestone covering the summit is cracked by reticulated fissures into rhomboidal areas, several hundred feet on a side. These fissures are very prominent, as their course is marked by a rich and luxuriant growth of grass and flowers, in strong contrast to the scanty covering of the limestones. The fissures are filled by a soft, olive-colored or greenish material that is a decomposed dike rock.

The dikes are commonly 1 to 3 feet wide, but the largest, which trends directly toward Yogo Peak, is between 9 and 10 feet wide. The decomposed dike rock commonly shows numerous mica plates, which lie in planes parallel to the sides of the dikes, giving the rock a flaky, fissile structure that is made prominent by weathering. The fresh material of one dike shows large, red olivines. These rocks are augite-minettes (or analcite-basalts), whose characters are fully described in the petrographic chapters. They weather peculiarly, as the micas alter to soft, green chloritic masses, which dot the rock with prominent spots.

Dikes of Eureka divide.—The low saddle between Bandbox Mountain and Steamboat Mountain also shows an interesting group of dikes. The sedimentary rocks seen on the divide above the Eureka mine are Carboniferous, belonging near the base of the Madison formation and containing an abundance of silicified fossil shells which weather in relief. These rocks are cut by a number of dikes—twelve were counted—nearly parallel and trending directly toward Yogo Peak. The dike rock is seen in all stages of alteration to a soft, olive-colored clay, and has been very generally prospected for ore deposits. The dikes vary from a few feet to a few yards in width. They are generally minettes, but include also a dike of analcite-basalt, similar in character to that cutting the summit of Bandbox Mountain.

WOODHURST STOCK.

In Sheep Mountain and eastward to Woodhurst Mountain the intrusion consists of a syenitic porphyry, and is no longer a coarsely granular rock. The general characteristics are the same, and the rock is to the eye the same in texture and composition throughout, though varying slightly in color. Under the microscope it is seen to present slight variations, but is throughout a syenite-diorite-porphyry, which passes into a rhyolite-porphyry at the extreme northeast contact. The rock is a general type common to the laccolithic masses of the range, and presents none of the remarkable variations in texture and composition seen farther east. It forms in rather massive exposures, but upon weathering the blocks break into platy débris, which frequently covers the exposures. On Sheep Mountain the igneous rock extends from a low saddle to a knob to the north, and also forms an eastern spur whose wooded slopes extend down to Bear Park. The intrusion continues in the low range of wooded summits north of Bear Park, extending as far as Woodhurst Mountain.

Structural relations of Woodhurst stock.—In the vicinity of the settlement of Yogo, as in Lion Gulch, the general structure of the sedimentary strata, due to the uplift of the range, as a whole is not disturbed; but east of here, in Bear Park and on Running Wolf Creek, local foldings due to laccolithic intrusions are noticed. It is, however, evident that the intrusive stock is not of this nature. East of Sheep Mountain successively higher horizons are cut, and in Bear Park, and again on the east footslopes of Woodhurst Mountain the Carboniferous shale (Quadrant formation) is cut by the igneous rock. At Woodhurst Mountain the channel of Willow Creek is cut along the eastern contact until the open country is reached. The contact at Woodhurst is chiefly with the massively bedded Carboniferous, but on the west face of the mountain a sharp upturning of the beds, as if a block of strata were hinged and lifted up, exposed what appear to be Cambrian limestones, though too altered for a positive identification. The beds dip away from the porphyry at 40° to 50°, and on the south side the massive Carboniferous limestones dip away from the mountain at 30°. These dips are opposed to those of the adjacent regions and the general mountain folding, and can be explained only by supposing a laccolithic uplifting at the place. The northern or northwestern edge of the porphyry mass shows gently dipping beds of Carboniferous limestone, the inclination being about 2°. It is evident that there must be a fault along the course of the creek. The contact is not regular, but breaks through different beds. The rock found in the eastern hill is platy, the edge being parallel to the slopes of the hill.

YOGO CREEK VALLEY.

Yogo Creek has cut a deep and narrow valley, whose southern slopes are so heavily timbered that few exposures are seen, while the slopes to the north show good exposures of the bedded rocks. To the south of the Yogo settlement the steep walls of Prospect Ridge rise nearly 2,000 feet above the creek. Near the top the Carboniferous limestones are seen to dip gently toward Yogo, though the ledges gradually descend the mountain slopes eastward. In Schoppe Mountain and Sheep Mountain, the two knobs that cap the lateral spurs of the main ridge north of the settlement, the slopes also show northward dipping beds, and at the mouth of Bear Creek this is the direction of the dip. A mile north of Yogo, however, this dip is reversed and the strata are inclined southward. The creek has cut through the limestones and exposes Cambrian shales from the mouth of Elk Gulch to Bear Creek. Above them the rocks are well exposed in the slopes north of the creek. Two sections were measured. The first, made during a snowstorm, may give slightly inaccurate thicknesses, as the aneroid could not be depended upon and the pocket level was useless. This section shows the succession of the beds observed in the slopes of Sheep Mountain immediately north of the town. The second section given was made on the spur between Bear and Yogo creeks. The Sheep Mountain section is given below. The beds dip at 10° up Skunk Creek—that is, into Sheep Mountain.

Section of beds exposed north of Yogo.

	Feet.
Porphyry sheet:	
Thinly bedded, massively weathering, gray limestone	250
Limestone, forming cliffs	50
Impure, buff limestone, forming three bands, separated by 20 to 25 feet of thinly bedded, dark-gray limestone	115
Massively bedded white limestone, weathering with prismatic jointing, breaking into splintery fragments, and carrying small cherts	35
Limestones, in beds 5 to 8 feet thick, dark gray, and containing fossils which weather in relief on faces of shaly rocks	400
Limestones, thinly bedded, impure and shaly; gray colored on fresh fracture, with reddish buff and lavender tones on weathered fragments. Numerous fossils	100
No exposure; porphyry sheet at 6,900 feet above sea level	100
Limestone; gray and light gray, dense, not crystalline, beds of light brown weathering buff, alternating with gray-weathering beds. The uppermost 75 feet is probably Carboniferous	190
No exposure	15
Black limestone containing calcite geodes	20
Black limestones. Forms base of Jefferson limestone series	30
No exposure.	
Yogo limestone	10
Dry Creek shale:	
Shales; micaceous, green and olive colored; of Cambrian aspect.	

Section at mouth of Bear Creek, Yogo Gulch.

	Feet.
Castle limestone:	
Limestones, in heavy beds of white, almost structureless rock, in which the sharp limestone canyons and gateways of the creek are cut. It is this bed that forms the canyon at Bear Park.	
Massive white limestone, underlain by a brecciated rock carrying dark-brown, cherty limestones in fragments 6 to 10 feet across. The rock shows glistening grains resembling sand, and passes downward into a dark-gray rock	200
Woodhurst limestone:	
Buttress limestone, weathering yellow, generally gray on fresh fracture, carrying scanty fossil remains, including crinoids, corals, and spirifers. The rock forms bold buttresses, but has shattered on weathering into small fragments 2 to 3 inches across	100
Limestone; dark gray, with crystalline fragments of crinoids and other fossils	200
Limestone, in massive beds at base, capped by less dense layers of limestone above. The rock is a gray, massive limestone, but its character varies at different parts of the same horizon, and is often yellowish and decomposed. The upper part forms sharp pinnacles rising above the slopes	125
Limestone, thinly bedded, very fissile	100
Limestone, gray and cherty, occurring in 2 and 3 foot beds	8
Thinly bedded limestones, striped with wavy bedding lines and carrying chert lenses parallel to the bedding. The rock is darkish gray and changes to a lighter-colored, more flaggy limestone 25 feet above the base. Dips at 30° into the hillside	75
Thinly bedded limestones, darkish-gray color, rather platy, and show abundant Carboniferous fossils	85
Cliff limestone, often broken into buttresses; heavily bedded with rough guttered surfaces; dark gray in color and in quite prominent layers	25
Darkish-gray, thinly bedded limestone, cherty, and carrying abundant fossils. This bed and the one above are seen in castellated masses at the mouth of a small easterly branch of Bear Creek, the stream draining the amphitheater of Ricard Mountain	45
Paine shale:	
Limestone, gray, red, and purple, rather massive, and breaking into angular débris	60
Fossiliferous gray limestone, probably argillaceous	1
Shaly limestone, like that below, carrying abundant fossils	75
Limestone, light brown, earthy colored, granular; without fossils	1
Threeforks shale:	
Shaly limestone, with reddish color, carrying fragments of small crinoids and resembling the Devonian horizon	15
No exposure, but débris of light-brown limestone.	
Jefferson limestone:	
Limestone, light brownish-gray in color, weathering pink; probably part of the bed below. The rock is a granular crystalline one that occurs in flaggy beds	20
Limestone, dark colored, granular, showing light markings a half inch long that look like scratches on the rock and appear to be characteristic of the formation	50
Limestone, dove colored, not crystalline, breaking into small fragments. No fossils seen	2
Black limestone, forming cliff ledge at edge of bench	25
Light, earthy-colored, fissile limestone, more argillaceous than that below	2
Earthy-colored limestone, broken down into slope	10

Jefferson limestone—Continued.	Feet.
Ledge of massive limestone, showing quite fine statification lines. The rock does not break readily along these lines of stratification, but has a jointing which is at angles to this	35
Limestone, light earthy color, blotched with pink; clearly a part of the ledge below	3
Black ledge, everywhere prominent. The limestone is crystalline, granular, and in the exposure is a glistening rock of very dark brown or black color, forming a persistent ledge that is readily recognizable. The rock has a fetid odor upon concussion, and the lowest 5 feet of the ledge is not black but an earthy-brown, rotten limestone	18
Yogo limestone:	
Light earthy-brown limestone, occurring in beds that break readily into splintery fragments 2 to 3 inches across	60
Shaly limestone of light earthy-brown color; really part of bed above	5
Dry Creek shale:	
Limestone, quite shaly, reddish in color, and weathering readily into red earths. It is really a laminated calcareous shale	25
Pilgrim limestone:	
Limestone, thinly bedded, but not shaly	20
Limestone, quite fissile, breaking into plates 1 to 2 inches thick, and forming ledge near creek	7
Limestone, conglomeratic, forms lowest ledge exposed	10
Laminated calcareous shales, occurring at the mouth of Bear Creek, where they are broken through by an intrusive sheet of minette	5

Sheep Mountain.—Sheep Mountain is the summit of a spur of the main ridge lying between Bear Park and Skunk Creek. The mountain is a synclinal fold, cut by a dike-like extension of the Yogo stock. The strata at Yogo dip north, while at the northern summit of the mountain the dip is south. A section of the sedimentary rocks has just been given. In the dikes seen cutting the west face of Sheep Mountain the contact is vertical and in nearly undisturbed limestone, while the eastern face of the same mountain shows that the contact is inclined and the igneous rock extends under the sedimentaries. The spur extending east to Bear Park shows porphyry flanked on the north by limestones dipping down the fork of Running Wolf Creek. The southern summit shows grassy slopes on top, with wooden spurs below, on which the porphyry débris and talus are seen extending down to Bear Creek.

This spur is surmounted by a knob formed of the platy débris of the porphyry, the contact being seen in the little saddle west of the knob, where the contact line is, as usual, prospected, and the pits show 2½ to 3 feet of specular iron ore between the crystalline limestones and the porphyry. The beds beyond this contact are dark-gray and bluish, thinly bedded limestones, showing the effects of the heat from the igneous injections in a markedly crystalline texture. These rocks are succeeded by very fissile, dark-blue limestones, dipping down the spur. The top of the mountain, which is the northern summit of Sheep Mountain, is of rather massively bedded white limestone. North of the summit the darker limestones appear, and 200 feet below it these beds are cut by a dike of basic rock 15 to 25 feet wide, the dike running toward Yogo

Peak. A second dike of porphyry was observed 400 feet below the top. The crest of the ridge is notched by a saddle or gap 600 feet wide and 600 feet or so below the top, which is cut in a soft and readily weathering basic rock (shonkinite). This lies alongside of or forms a part of the porphyry extending up the slope to a point 200 feet above this saddle, the contact between the two rocks being marked by a mining shaft showing 2½ feet of iron ore (hematite). The rocks are rather poorly exposed, and the soil and vegetation prevented a determination of the exact relation of these rocks to one another. Beyond the porphyry the sedimentary rocks form the slope up to the summit of Bandbox Mountain, but are cut by a dike of shonkinite, on which a shaft has been sunk. The saddle between Running Wolf and Skunk creeks shows the usual contact marbles cut by two basic dikes. Two prospect shafts have been sunk in the contact, 150 or 200 feet below the summit on the Wolf Creek side.

The stream west of Sheep Mountain, which is known as Skunk Creek, has a wide basin at its head, which is well wooded and thickly soiled, so that the rocks are generally concealed. A wagon road has been cut in the slope from the prospects west of Bandbox Mountain down to the Yogo settlement, but the cuts show only red shaly débris until near the Weatherwax mine, where porphyry is seen.

RICARD MOUNTAIN.

Ricard Mountain is a detached elevation lying east of the mountain ridge formed by the Yogo stock. It is a laccolithic uplift in which the intrusive has broken irregularly through the various Paleozoic horizons. The mountain is a dome shaped anticline, the limestones of the Carboniferous dipping steeply away from it in every direction. This dip being somewhat greater than the angle of the slopes, successively older and older beds are seen in ascending the slopes, and the beds exposed on the summit are still older than those on the flanks of the mountain. The dip flattens on the northern spur, the beds being nearly level 1,000 feet above Bear Park, so that this may be taken as the center of the arch. In the saddle north of the highest summit the beds dip north at 23°, and on the eastern spur the eastward dip is 20°. On the western face the small stream which is cutting its way into the anticline exposes the underlying black limestones with a central area of red shales supposed to belong to the Cambrian rocks. It is evident that the main body of the laccolith forming the core of the mountain is either in the Cambrian or beneath it, and that the igneous rocks seen on the summit are merely offshoots of this concealed core.

The summit of the mountain is formed of several knobs separated by depressions several hundred feet below the higher point. The rocks are Carboniferous limestones containing an abundance of fossils, and varying from a thinly bedded and flaggy, dark-brown limestone to the blue, compact limestones which lie beneath the massive white limestones that are the most conspicuous feature of the Carboniferous terrane. The southern summit is cut by a pipe or dike of quartz-porphyry that is several hundred yards wide and is marked by an abrupt contact, in which 25 feet of limestones, altered to coarsely crystalline marbles, separate two sheets of rhyolite-porphyry, one 15 feet and the other 20 feet thick, from the surrounding limestones. The porphyry mass forming the summit weathers in small angular chips, and is altered so that quartz and an occasional large phenocryst of feldspar are the only minerals seen. This rock extends from a point just east of the saddle separating the main peak of the knob to the west, up to the summit, and along the summit for a quarter of a mile eastward. The northeast spur of the mountain shows a sheet of rhyolite-porphyry, intrusive in the massive limestones, which has been denuded and now caps the ridge.

RUNNING WOLF RIDGE.

The ridge extending east from Bandbox Mountain, and lying between Running Wolf and Galena creeks, is a block of tilted massive limestone strata, dipping eastward. The dip, which is 13° on Bandbox Mountain, becomes gradually flatter toward the east. An intruded sheet of porphyry caps the ridge near its center, and several dikes and sheets are seen both in Running Wolf Valley and on the summit of the ridge, especially near the collection of log cabins belonging to the Woodhurst-Mortson mine. (See Pl. LXVIII.)

While the general dip of the beds is down the ridge, yet the north side shows an inward or southerly dip. This is due to the Steamboat Mountain uplift, the axis of the anticline thus formed running nearly parallel with Running Wolf Creek, along the edge of the ridge south of it. Several mining prospects have been found just north of this line, and the Woodhprst-Mortson mine is similarly situated. A porphyry sheet is seen outcropping east of this mine, where it forms a talus slide, but was not seen west of the mine. The strata at this locality dip at 25° into the ridge, and strike very nearly with it. On the summit the beds are more gently inclined. The surface, which is covered by open woods, and rises gradually to the west, terminates southward in precipitous cliffs.

Minette intrusions.—A half mile or so from the Woodhurst mine the bluish-black limestone bed covering the summit is cut by two dikes running transversely across the ridge. Farther west a third dike of basic rock is seen on the summit. The rocks are augite-minettes, which weather to soft greenish or rust-colored materials, from which fresh unaltered material can seldom be obtained. The freshest specimens are green and contain large augite crystals.

In ascending the ridge lower and lower beds are successively exposed to the knob or summit of the ridge. In the saddle between this summit and the steep slope of Bandbox Mountain thinly bedded blue limestones have a strike of N. 50° W., and dip 20° NE., apparently with the ridge.

The sag is due to an intrusive mass of basic rock, whose exact nature could not be determined, though it is probably a sheet. The rock is quite altered and rotten, but is recognizable as a minette by its abundant mica. It holds included masses of the shaly limestones in the center, which are altered to hornstone and cut by stringers of the igneous material. The outcrop is 60 feet across. The rocks at the borders show considerable induration and metamorphism.

Similar intrusions of minette were observed at the mining cabins in the creek bottoms below the Woodhurst mine, the rock being a much altered augite-minette and forming an intrusive sheet dipping south at 20°, conformably with the limestones, and showing on both sides of the creek. This is cut by a 6-foot dike of similar rock which appears 100 feet above the creek on the slope to the south, and which trends northeast and southwest, the direction of Yogo Peak.

SAGE CREEK MOUNTAIN.

Like Ricard Peak, this mountain mass is a partly stripped laccolith. The mountain shows a central mass of igneous rock, surrounded by massively bedded white limestones, which dip away from the mountain at steep angles on all sides. The drainage ways which score its sides carry water only where cut in the porphyry, being dry in the limestone areas. The porphyry slide covers the eastern knob of the mountain. The mountain is precisely similar to Ricard Peak in structure, but the massive limestones are not yet cut through, and so far as seen are the only rocks exposed. As this mass lies so near Ricard Peak, there is a sharp and sudden upturning of the limestones between the two mountains, and Sage Creek flows along a synclinal fold.

STEAMBOAT MOUNTAIN.

This mountain shows a laccolith just emerging from its cover of sediments. The mountain flanks show the massive beds of Carboniferous limestone dipping away on all sides from the central peak. The dip is steepest near the summit, where it approximates 30°, and lessens rapidly as the distance from the summit increases. The southern slopes show the Cambrian and Devonian rocks lying beneath the laccolith and the Carboniferous. The northern slopes were not visited, but the laccolith appears to lack symmetry and to be in contact with the Carboniferous on that side. The saddle between Steamboat and Bandbox mountains, at the head of Running Wolf Creek, shows a sharp synclinal folding of the limestones where the northerly dipping beds of Bandbox are uptilted and the dip is reversed by the Steamboat laccolith. To the northwest of Steamboat the broader uplift, caused by a concealed intrusion east of Big Baldy, limits the upturning on this side.

The laccolith appears to be intruded mainly in the soft shales of the Cambrian. These rocks are considerably metamorphosed at or very near the contact with the igneous rock, forming dense and glistening black schists, dense hornstones, and those garnet-calcite aggregates and other common forms produced by contact metamorphism. The Monarch limestones (Devonian) and the Carboniferous, being farther from the igneous rock, are less profoundly altered, though they show in their texture and color the influence of the metamorphic processes. The highest part of the summit is formed of these altered rocks. The laccolith rock is a diorite-porphyry. It is dark gray in color, and to the eye closely resembles the porphyries of Sheep, Woodhurst, and Sage Creek mountains, though darker in color. Under the microscope it has the same general habit, but the plagioclase feldspars predominate. It forms a platy débris, covering the summit, which, even where wooded, shows little soil.

The mountain slopes, when viewed from a distance, show the laccolithic nature of the uplift very plainly, the limestone beds forming curved sheets wrapped about the flanks, as shown in the accompanying diagrammatic sketch (fig. 40). The succession of strata is best seen in the saddle to the south, the narrow ridge showing good exposures. The rocks are here cut by twelve or more basic dikes, radiating from Yogo Peak, as already noted. The débris of a similar rock was found on the summit of the mountain, and is probably derived from a similar dike. An offshoot of the laccolith breaks across and through the tilted rocks near the south contact, the rock being quite similar to that of the main laccolith.

The southern spur shows a small fault when seen from the summit of Bandbox Mountain, the fault plane dipping very steeply to the north, the downthrow on that side being estimated at less than 100 feet. This was not observed when the ridge was visited, and is probably recognizable only in the cliffs forming the west face of the ridge. It is the only instance noted in the laccoliths of the range in which the cover shows faulting, other than that due to general asymmetry of the intrusion.

The largest southerly spur of the mountain is that on which the Sir Walter Scott mine is situated (see p. 451). The altered Cambrian rocks exposed on this ridge show three intrusive sheets of porphyry between the summit and the saddle back of the knob on which the mine is situated. South of this saddle a lesser knob, formed by a porphyry sheet and another sheet estimated to be 300 feet thick, lies between the Cambrian and Devonian rocks. The rocks of this spur are cut by several dikes of the dark trap rocks, similar in character to those of the Eureka divide at the head of Running Wolf Creek, and believed to be extensions of the same dikes. The same minette rock was observed in the dump heap of the mine just mentioned.

The northern base of Steamboat Mountain ends in the limestone cliffs of Wolf Creek. The dip is gentle, and exposes successively higher and higher beds as one travels from Lion Creek northward. Porphyry is seen but 200 to 300 feet above the limestones which cross Dry Wolf Creek and run up the walls east of Butcherknife. This porphyry is seen on the western spur of the mountain but a few hundred feet above the creek, while on the northern spur of the mountain limestone beds dipping at 30° away from the peak are seen at least 500 feet higher. These exposures were not visited, but the relations are plainly visible from the opposite side of the valley, and the elevations were determined by hand-level measurement. It is assumed that the porphyry seen is the edge of the laccolith, which on the north side of the mountain has therefore broken up through the Carboniferous beds.

BIG BALDY MOUNTAIN.

DESCRIPTION OF THE PEAK.

The highest mountain of the range is Big Baldy. Its bare, smooth, dome-like summit rises to a height of 9,000 feet above tide water, and forms a conspicuous feature of the region. Like all the more prominent mountain masses of the range, it is formed of igneous rock, a variety of granite-porphyry designated the Barker porphyry. This rock here forms a great mass 3 miles wide and 4 miles long, with a vertical thickness exposed of 2,000 feet. The uniform character of the rock indicates that it constitutes a single body and is not the result of several intrusions.

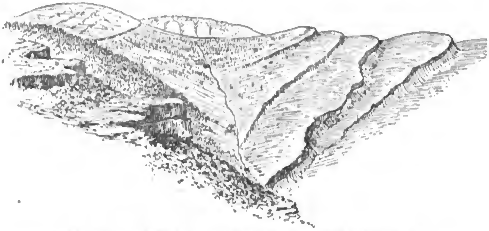


FIG. 40.—Strata flexed by Steamboat Mountain laccolith, Eureka divide.

On three sides this igneous mass is surrounded by stratified rocks, whose general attitude is that due to the uplift of the range, the beds being only locally disturbed by the intrusion. The broad arching of the strata seen in the laccolithic uplifts already described is not seen here. The contact plane is not generally well exposed, but the relations of the stratified rocks, as shown in the cross section (fig. 41), indicate that the contact is nearly vertical, and that the instrusion is of the type of laccolith first named and described by Professor Iddings as a bysmalith.[1] On the west the igneous rock is in contact with the crystalline schists, but there is no evidence of a fault or equivalent fold in the continuation of this contact line into the areas of stratified rocks.

The source of the intrusion is not known, but the nearness of the Yogo Peak center of igneous activity and the peculiarities of the Big Baldy rock show a close relation with that stock, and indicate that the intrusion is but one of the many masses associated with and forming part of the Yogo epoch of igneous activity. The observed relations of the mass to the adjacent rocks indicate that it is the result of the intrusion of a magma rising through a conduit in the gneiss and spreading out in the shaly beds forming the base of the Cambrian. The overlying rocks were lifted and arched; but, fracturing about the borders of the intrusion, were pushed upward as a dislocated block and raised 2,000 feet above the original position. The grain of the rock, which is similar to that of the laccolithic rocks of the range, is very uniform, and the crystalline texture indicates that the magma solidified beneath a covering of rock, now denuded.

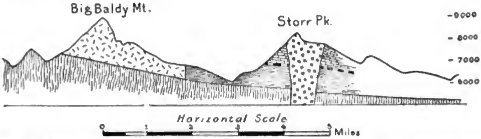


FIG. 41—Northwest-southeast section through Big Baldy Mountain and Storr Peak. Scale on right shows height above sea level.

The dome-like outline of the mass is but slightly altered by erosion, and is seen in the profile of the mountain from most points of view, as shown in Pl. XLVII, *A*, and Pl. XLVIII, *A*. The northern slopes are smooth and rounded, but are slightly scored by gullies, and may represent the denuded and as yet slightly altered surface of the intrusion. To the south the summit is indented by two deeply cut amphitheaters, but the intervening spurs still preserve a gentle slope and rounded surface, like that of the northern side of the peak. The diagram above (fig. 41) shows the profile as it appears from Yogo Peak, the accompanying plate (Pl. XLVII, *A*) being made from a photograph taken at that place.

The summit slopes are everywhere smooth, rounded, and covered by platy débris, no massive exposures being seen until the actual summit is reached. The two immense amphitheaters cut in the southern side of the summit show magnificent exposures of the rock in their precipitous walls. The accompanying illustration (Pl. XLVIII, *B*) shows the massive weathering of the rock. The great blocks seen in this view

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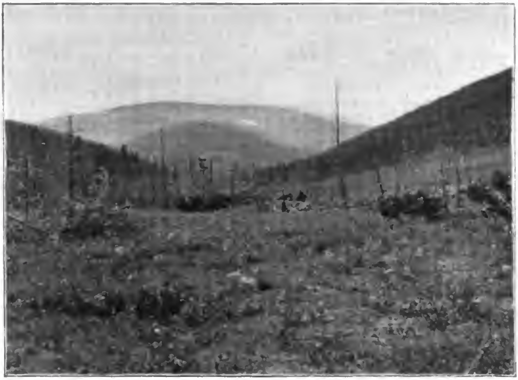
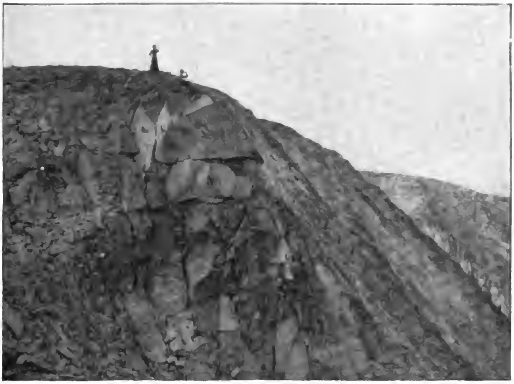
[1] Journal of Geology, October-November, 1898.



A. BIG BALDY MOUNTAIN, FROM HEAD OF CARPENTER CREEK

Showing rounded summit of stripped and as yet slightly eroded bysmalith



B. CLIFFS OF BARKER PORPHYRY, WALL OF WESTERN AMPHITHEATER OF BIG BALDY MOUNTAIN break readily, on falling from the cliffs, into platy masses, often several feet across and but a few inches thick, and this débris accumulates in great talus slides at the base of the cliffs and fills the bottoms of the amphitheaters. The walls are not uniform surfaces, but show sharp projecting buttresses and intervening débris slides. A lakelet fills a hollow in the bottom of the amphitheater surrounded by talus heapings, overgrown with stunted alpine pines. If these heapings are morainal they constitute the only evidence of glaciation observed in the range.

THE IGNEOUS ROCK.

The rock has a light-gray or purplish-gray color, which weathers with a reddish tinge. It is clearly feldspathic, and shows very prominent rectangular cross sections of a fresh, glassy-looking orthoclase feldspar, embedded in a dense groundmass dotted with small opaque white feldspars and a peppering of minute black grains of hornblende and biotite. The rock is quartz-syenite-porphyry, but is related to and mapped as a phase of the Barker granite-porphyry. It is fresh and unaltered, and contains occasional small inclusions of gneiss, shale, limestone, and minette, which are apparently but little altered. The rock is very similar to those forming the eastern part of the Yogo stock; i. e., at Bear Park, Woodhurst Mountain, etc. Its character and affinities to these rocks are fully discussed in the accompanying paper by Professor Pirsson.

DIKES IN PORPHYRY MASS.

This rock is cut by dikes, but owing to the platy débris covering the summit their outcrops are obscure on the mountain top. The walls of the eastern amphitheater of the peak show several black dikes cutting the light-colored porphyry; and the débris, of a dense, very dark rock, which proves to be an analcite-basalt, occurs strewn over the southwestern slope, mixed with the porphyry. Two dikes of lighter color than the porphyry of the amphitheater walls are recognizable to the west of the black dikes seen on the west side of the eastern amphitheater.

INTRUSIONS IN SURROUNDING STRATA.

Numerous dikes and intrusive sheets occur in the stratified rocks about the mountain, especially in the easily invaded Cambrian shales. Where these sheets have been actually located they have been shown on the map, but there are probably other sheets not exposed or extensions of the sheets mapped at localities not visited. They belong to the two groups of feldspathic and basic (trap) rocks, and are in the main regarded as offshoots of the Yogo Peak center, except in the case of the thick sheets exposed by Wolf Creek at the southwest base of the mountain, where their connection with the Big Baldy mass is probable. The occurrence of these intrusions is noted in the succeeding pages, together with that of the stratified rocks in which they are intruded.

The relation of the Big Baldy mass to the surrounding rocks has already been summarized. To the north the drainage channel of the head of Dry Fork of Belt Creek is cut along the contact and separates the porphyry from the Archean gneiss, which forms a rough, hilly district. To the west the ridge running to Neihart Mountain (Long Baldy) shows the same red and gray gneiss.

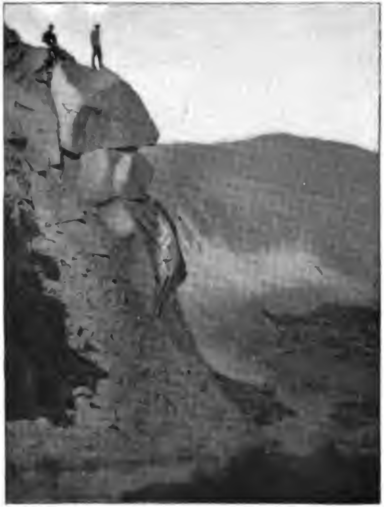
BELT CREEK DIVIDE.

South of the mountain a narrow ridge dividing Wolf and Belt creeks shows thinly bedded Cambrian shales, with numerous conformable intrusive sheets of igneous rock. The strata at the immediate contact with the porphyry are somewhat, but not profoundly, altered, forming a hard, dense, blue, shaly débris that obscures all massive exposures. An offshoot of the main intrusion cuts these rocks. The first good exposures seen near the contact are hardened shales and conglomerates that dip at an angle of 3° toward the peak. South of the little sag that defines the mountain slopes from the ridge the same beds dip south at a low angle. The knobs or summits along the ridge are capped by porphyry, and the sheets form crescentic benches on the slopes. The ridge has a general descent to the south, so that a single sheet may appear on the top of one of these knobs and reappear on the slopes to the south.

The western spurs of this divide ridge are generally grassy or but sparsely wooded slopes, on which the intruded sheets form benches and little cliffs. The intervening shales weather down to a slope showing no exposures, except where locally hardened by contact metamorphism alongside of the intrusive masses. The spur visited showed eight intrusive sheets in a total thickness of 700 feet of shale. Two of these sheets are minettes; the others are feldspathic rocks varying somewhat in character as in thickness. The lower four acidic sheets are characterized by hornblende. The rocks are much altered and break readily into a platy débris. The map shows these sheets only upon the spur visited, but it is probable that they occur in the adjacent ridge, as the persistency of the sheets intruded in the shale is a very striking feature of the region. The thicker sheets have produced considerable metamorphism of the shales near the contact. A sheet 75 feet thick, occurring 400 feet below the top of the ridge, has baked and hardened the shale for 10 feet from the contact. These sheets, together with the inclosing strata, dip at a low angle to the west on the upper slopes, but this is reversed on the lower slopes, the dip being east, or toward the main divide, at 3° to 5°, conforming to the general dip that prevails down Belt Creek. That this is the general dip of the beds forming the divide is proved by the attitude of the same rocks exposed east of the ridge, about the head waters of Wolf Creek, where the dip is also east.

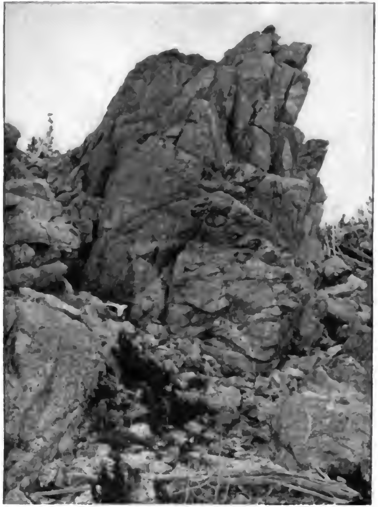
SOUTH AND EAST FLANKS.

The eastern spur or shoulder of Big Baldy, which ends at the Big Park of Wolf Creek, shows good exposures of the bedded rocks, dip-



A AMPHITHEATER CUT IN EASTERN SIDE OF BIG BALDY MOUNTAIN.

Showing lake in bottom, dammed by talus that slides down over snow banks—a pseudo-glacial lakelet.



B PINTO DIORITE EXPOSURE, HEAD OF ROCK CREEK, NEIHART.

Showing mottled ("Pinto") surface of weathered rock.

ping at a low angle away from the peak. The contact between them and the igneous mass is defined by a shallow notch or sag at the head of a small drainage way tributary to the stream from the eastern amphitheater of the peak. The highest beds are the massive Carboniferous limestones, whose bold ledges are seen dipping at 6° away from the peak in the western face of the spur.

BIG PARK.

Big Park, as the meadows of Dry Wolf Creek together with the thickly timbered upper valley of that stream are called, is so closely connected with the Yogo Peak mass that it may properly be treated here. The lower parks of the creek are bordered by steep walls of limestone. The beds dip at a low angle (8°) down the creek, and as one ascends the stream successively lower horizons are passed, until near Lion Creek the white limestones of the Carboniferous are seen underlain by the dark-brown beds of the Jefferson limestone. As usual about Yogo Peak, the shales are intruded by sheets and dikes of various rocks, offshoots of the Yogo Peak center of igneous activity. In Lion Gulch the shales are seen overlain by limestones, and the mineral deposits of the gulch are found at the contact between the brown Jefferson limestone and an intrusive sheet of porphyry, about 150 feet below the base of the white limestone series. Big Park is due to the widening of the valley of Wolf Creek, owing to the presence of the Cambrian shales. A measured section was made of the beds exposed on the eastern end of the spur, which forms the steep slopes west of Big Park, opposite Lion Creek.

Stratified rocks exposed in north wall of Big Park, opposite Lion Creek.

	Feet.
Carboniferous limestones, 1,400 feet above creek; fossils, Fenestella, crinoids, brachiopods; all of typical Carboniferous aspect	150
Paine shale:	
Limestone, bluish and hard	?
Limestone, shaly, dark colored	290
Limestone, shaly, light colored	
Jefferson limestone:	
Limestones, black; top of bed forms bench	75
Limestones, granular, crystalline, black, Devonian aspect	
Limestones, massively bedded, light colors, pitted and rotten looking, often pinkish and gray	35
Limestones, bluish, but not black	100
Felsite-porphyry sheet	24
Limestone, buff weathering; light brown on fresh fracture; Devonian aspect	15
Limestone, dark blue	25
Intrusive sheet	15
Limestone, Jefferson facies	10
Yogo limestone:	
Limestone, thin-bedded, very dense, blue-gray rock, in beds of 2 to 4 inches	65

Yogo limestone—Continued.	Feet.
Limestone bed, very persistent, and forms ribbon-like line along slopes; always weathering out	1½
Limestone, rotten, buff-colored rock, breaking with irregular fracture	10
Dry Creek shales:	
Shales, red and purple, with impure, yellow, thinly bedded limestones	40
Pilgrim limestone:	
Limestone, purple colored and shaly	45
Limestone, massive, blue, weathering yellow and rough; irregularly flaggy	25
Park shale:	
Red shaly beds	115
Meagher limestone:	
Limestone and conglomerate	300
Intrusive sheet of igneous rock (5 feet).	165
Wolsey shale:	
Shales, micaceous, forming wooded slopes without exposure	
Intrusive sheet of igneous rock (15 feet).	
Shales, soft, micaceous	
Intrusive sheet	
Shales, micaceous.	

The intrusive sheets and dikes noted in this section were the only ones examined on the eastern flanks of Big Baldy Mountain. The lowest sheet is traceable along the base of the slope for a mile or more to the southwest, but is carried by its dip beneath the meadows to the north. The rocks are like those already described as forming the encircling sheets of Yogo Peak, and the different sheets exposed in this section also occur intruded at the same horizons across Big Park, 2 miles southwest of the mouth of Lion Creek. A still lower mass of nearly white intrusive rock is seen on the banks of the creek at the upper end of the park, where it forms white talus slopes. Going southward this sheet is seen to be over 100 feet thick, and west of the creek forms a ridge coming from the eastern amphitheater of the mountain. Its extent is not definitely known, but must be considerable. The rock is a dense, white rhyolite-porphyry. That the rock is a sheet is clearly seen at the point at which the stream from the Big Baldy amphitheater joins Dry Wolf Creek, where Cambrian shales are exposed underlying the rhyolite-porphyry. The igneous rock only is seen above, where it forms hillocks and débris piles extending northward.

HEAD WATERS OF DRY WOLF CREEK.

West of the stream from the western amphitheater of the mountain the trail up Dry Wolf Creek traverses a densely timbered bench or slope, on which there is much quartzite and porphyry drift, but no rock is found in place until the trail leaves the creek and ascends the spur that extends east from the Belt Creek divide. Here the porphyry, through which the little gorge of Dry Wolf has been cut, is overlain by red Cambrian quartzite and sandstones 200 feet thick, capped in turn by a sheet of porphyry 200 feet thick. Above this the Cambrian shales, with several intruded porphyry sheets, extend to the top of the divide, a total thickness of 1,400 feet. The beds dip east at a low angle, so that the quartzite must pass beneath Wolf Creek not far above the mouth of the amphitheater drainage. The horizon of the Big Baldy intrusion is therefore lower than the basal Cambrian quartzite at this point.

ORE DEPOSITS.

There are no mines on Big Baldy Mountain, but the flanks have been prospected at many places near the contact. The rocks of the summit are generally weathered, but otherwise unaltered, and it is with surprise that one observes the boundary stakes and shallow open pits of mineral claims. Thin seams of iron-stained material, said to contain traces of gold, were observed, but nothing to indicate the presence of valuable mineral deposits.

BUTCHERKNIFE MOUNTAIN AND CREEK.

The mountain (7,821 feet in height) north of Big Baldy is formed of sedimentary rocks, which arch over and conceal a laccolithic center of porphyry. The eastern side of the mass is deeply cut by the drainage of Butcherknife Creek. Butcherknife Gulch was not ascended. The stream gravels show an abundance of syenite- and rhyolite-porphyries, the former being the common type found in the intrusive sheets of the region. A dark-green, almost black, rock, which microscopic study proves to be an orthoclase basalt, forms peculiarly pitted bowlders. The most noticeable feature of the stream drift is, however, the abundance of dark-bluish hornstones, very hard and dense forms. This is the more noticeable because it is the only place about Big Baldy where such products of contact metamorphism of the Cambrian shales is noticed. At the mouth of Butcherknife Creek the limestones are nearly level, but the walls east of that creek show these beds dipping away from Big Baldy Mountain, the angle increasing northward and the beds rising higher and higher up the slopes, the dip being fully 30° on top of the ridge.

WOLF BUTTE AND TAYLOR PEAK.

From the open country of the Judith Basin, Wolf Butte appears as a sharply defined conical mass, situated in front of and a little distance from the wooded slopes that mark the general front of the range. This very prominent peak is formed of granite porphyry that is part of an intrusive mass extending southward for 4 miles and having a width of 2 miles. This intrusion has arched up the beds about it on the south, and, in fact, the limestones which surround it dip away from it on all sides, so that the mass probably constitutes a laccolith, though an asymmetric one—like all the other intrusions of this character seen in the range. To the south the Barker wagon road follows the synclinal trough produced by the meeting of the limestones dipping toward it from the mountain to the south and from Taylor Peak to the north. This trough preserves inliers of the Carboniferous shales which form the meadows at the south base of Taylor Peak and the foothills east of the peak. Taylor Peak itself is formed of massively bedded, Carboniferous limestones, dipping westward at 15°.

The Wolf Butte mass of igneous rock is seen in contact with the Carboniferous limestones except on its southern side, where, on the saddle north of Taylor Peak, the older rocks are seen sharply upturned, slipped, and intruded by sheets of porphyry, but clearly recognizable despite the alterations due to contact metamorphism. In this saddle the brown Monarch limestones and 400 feet of the jasper-ribbed Cambrian rocks are very easily recognized, though the dips increase from 15° in Taylor Peak to an almost vertical attitude at the contact, and the slipping of the upturned beds along shale horizons has resulted in the absence of such beds in the section seen at the contact. The Cambrian rocks in particular are toughened, baked, and hardened, and show contact minerals, especially in the joint and bedding planes. The uplift is progressively less and less northward, and at the base of Wolf Butte, at 5,600 feet, or 1,400 feet lower in elevation than the exposures just noted, the igneous rock is in contact with the shales and sandstone beds of the Quadrant group.

The laccolith rock.—The intrusion consists of granite-porphyry of a normal character, which has been given the name of Wolf porphyry to distinguish it from the very different-looking rocks of Barker Mountain and the other laccoliths of the region, rocks which are also granite-porphyries, though of a very different type.

The Wolf Butte rock is a coarse-grained porphyry, weathering with a massive jointing, splitting into immense slabs, and making crags and slopes and castellated forms that resemble those of a typical granite. The rock disintegrates readily to a coarse sand, so that it is not transported far. It shows large crystals of glassy quartz and pinkish orthoclase feldspars, with minute scales of dark mica. The prominence of Wolf Butte is due to the variation in the grain and jointing of the rocks and its consequent resistance to weathering, the rock being somewhat denser and more massively jointed than the more granular, easily disintegrated rock forming the amphitheater between the butte and the mountain south of it. The Wolf Butte contact with the limestones is abrupt and shows but little uplifting of the sedimentary rocks. The peak between Wolf Butte and Mount Taylor is formed by part of the contact rim of the intrusive mass, in which the rock is so dense as to constitute a rhyolite-porphyry. The rock is pinkish or brown and has very pronounced laminations parallel to the contact plane. It breaks with a platy fracture into thin and rather small fragments, and this platy parting breaks across the laminations. The upturned strata at this south contact of the laccolith contain several intrusive sheets of dark micaceous rock, resembling minette.

Intrusive sheets near Wolf Butte.—There are several intruded sheets of porphyry in the areas of Carboniferous shale south of Taylor Peak, but the character of the rock and manner of occurrence do not connect them with the Wolf Butte mass, but rather with the intrusions of the Barker type of porphyry. These sheets occur along the Barker wagon road, at the head of Arrow Creek, and in the hills north of Geer. At the first locality the beds are nearly horizontal and the porphyry is too much altered for study. In the foothills lying southeast of the laccolith the shales are intruded by two sheets of quartz-diorite-porphyry, resembling a variety of the Yogo stock rock. The lower sheet is, perhaps, 200 feet thick, and can be traced for several miles, forming a distinct bench on the smooth shale slopes. The upper sheet is thinner and caps the knobs or summits of the hills. The rocks resemble those of the east end of the Yogo stock, showing large feldspars and hornblende prisms in a gray groundmass. The rock weathers with a reddish surface and breaks in platy masses, leaving rounded exposures. It is cut by two minette dikes, which are therefore younger.

Ore deposits.—But one mineral prospect was examined. This is situated on the knob southeast of the saddle separating Taylor Peak from the mountain north of it. The prospect is on an east-west fissure, and shows galena and cerusite, together with malachite, azurite, chalcedony, calcite, etc.

Dry Wolf Creek dome.—Dry Wolf Creek cuts a canyon through a low dome of Carboniferous limestone that rises above the open grass land formed by the shales of the Quadrant formation. The rocks dip away symmetrically on all sides from the dome, whose structural relations are such that it seems very certain that it is formed by a concealed laccolith of igneous rock.

CHAPTER V.

DESCRIPTIVE GEOLOGY OF THE BARKER AND MONARCH DISTRICTS.

BARKER DISTRICT.

DISCOVERY AND DEVELOPMENT.

The Barker district is situated in the northern part of the mountains, on the headwaters of the Dry Fork of Belt Creek. The discovery of ore deposits, in the years 1875 to 1880, led to the rapid development of the district, and the towns of Barker and Hughesville were built. Several mines yielded large amounts of silver-lead ores from 1880 to 1883, but the inaccessibility of the region and the high cost of transportation to smelting centers constituted a serious detriment to the development of the camp. A smelter was erected at Barker in 1881 and ran for a short time, but the ore bodies first discovered proved to be limited in extent, and when the Neihart deposits were developed in 1884 the camp had seen its best days. The completion of the branch railroad to the camp in 1888 and the building of the silver smelter at Great Falls gave a temporary impetus to mining development, but as the ores are valuable only for their silver contents the place was practically abandoned when the drop in the price of silver occurred in 1893. In 1894 the Tiger and Moulton mines were the only ones being worked, and these only on a small scale under lease. From that time to 1897 the mines were worked for short periods at various intervals and by different leasers until the demand for lead ores at the smelters and the granting of cheaper rates for smelting and railroad charges led to an active prospecting of old and new properties. At the present time the future of the camp looks more promising than at any previous period of its history.

EXTENT AND TOPOGRAPHY.

The Barker district proper embraces the basin-like area lying north of Dry Fork of Belt Creek, as shown on the map (fig. 42), and inclosed between Barker Mountain on the west, Clendennin on the north, and Mixes Baldy and the adjacent peaks on the east. The basin is drained by Galena Creek, on whose banks the settlements of Barker and Hughesville are situated. The mountain slopes were formerly densely timbered, but about Barker the trees were long ago cut for burning into charcoal, and to-day the stumps and young pines cover considerable tracts, and the slopes north of the basin show a forest of bare, gray poles, the result of extensive forest fires. Rock exposures are nowhere prominent, and the country is not rough or especially rugged. The limestones show on Barker Mountain and are prominent where the wagon road crosses the divide to Otter Creek and the Kibbey Basin. The igneous rocks are more often exposed, but are seldom seen in conspicuous exposures except on the bare mountain tops. They form extensive débris slopes north of the basin, and intrusive sheets form low cliffs along Dry Fork of Belt Creek. The best exposures of the great limestone series are seen on the outer slopes of the mountains that inclose the Barker Basin.

The town of Barker lies at the lower end of this basin and only a short distance above Belt Creek. The old smelter and the charcoal kilns were built alongside Galena Creek, below the fork of this stream known as Gold Run. These, together with the Carter mine opposite the mouth of Gold Run, determined the site of the town. The principal mines were, however, farther up the basin—at its northern head, in fact—and another settlement was established there, which was given the name of Clendennin on the maps, but was commonly called Hughesville by the miners, and is still known by that name.

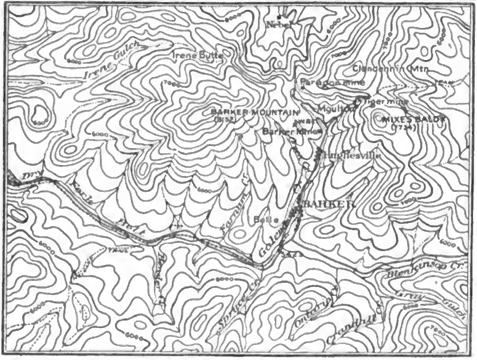


FIG. 42.—Map of Barker district.

The railroad was not extended to the mines, but terminates at the mouth of Galena Creek. The line has not been operated regularly for some years, although trains are run from the junction with the Neihart branch at Monarch whenever there are a few carloads of ore ready for shipment. Well-graded wagon roads run down Dry Fork of Belt Creek to Monarch, northward over a low pass to Otter Creek and the Kibbey Basin, and eastward up a branch of Belt Creek and over the divide to Arrow Creek and Dry Wolf Creek and the Judith Basin. The region is nearly as high above the sea as Neihart, but receives less snowfall and has a somewhat milder climate. The soft natures of the Cambrian shales and the crumbly weathering of the igneous rocks that prevail in the center of the basin give smooth and rounded contours, and open, rather broad, and retreating slopes. The eastern branch of Galena Creek, which joins that stream at the settlement of Barker, is known as Gold Run. A fork from the west, entering above Barker, is called Green Creek, while its two head-water branches unite at Hughesville, the settlement 2 miles above Barker, one fork coming from Kibbey Gap, the other forming the gap north of Mixes Baldy. This will be made clear by reference to the map, fig. 42.

The principal ore deposits discovered thus far lie at the northern border of this basin-like area, on the head waters of Galena Creek. There are also prospects along Gold Run and south of Dry Fork of Belt Creek, and one mine on the eastern bank of Galena Creek opposite Barker yielded a large amount of ore in the early history of the camp. The rocks show no very extensive areas of decomposition. Though changed by weathering and the ordinary processes of rock alteration, profound alteration of the rocks accompanying the ore deposits is confined to small areas immediately adjacent to the veins. The ore deposits all occur in connection with the igneous rocks which break through and have folded the sedimentary rocks.

The geology of the district is more varied than that of any other area of equal extent in the range. The district is situated on the northern border of the Archean core of the range, where the uplift of the mountains has upturned the sedimentary rocks and tilted them northward. This normal tilting is, however, almost destroyed by the igneous intrusions of the district. These are of various rocks, and occur intrusive in various ways. Barker Mountain is a great mass that is laccolithic in character, and has lifted up the sediments about it in a dome. Otter Mountain to the north is another laccolith which is as yet but partially revealed by erosion. Its sheets form Clendennin Mountain, whose slopes make the north wall of the Barker Basin. Mixes Baldy, the mountain to the east, and the peaks adjacent to it, are carved out of an intrusive mass punched through the strata—a great bysmalith. The center of the basin is occupied by a small stock of granular rock that may be the center of the igneous activity of the region.

SEDIMENTARY ROCKS OF BARKER DISTRICT.

The stratified rocks of the Barker district and vicinity present no features of especial interest. The different formations from Cambrian to Mesozoic are well developed, and exhibit the general sequence already described as common for the northern part of the range. The lowest beds, the basal quartzites, which rest upon the crystalline schists, are seen on the slopes south of the Dry Fork of Belt Creek, and where a bend of this creek, below the railroad terminus, cuts through the schists. In general the basal beds are indurated sandstones, sometimes true quartzites in nature, which consist of feldspar and quartz. The colors are, as usual, pink or reddish, weathering rusty brown. The rock sometimes grades into a conglomerate, but the latter form is neither common nor of more than local development. Cross bedding is often prominent. The rock is jointed and breaks into angular débris, but this is never abundant enough to be of more than local interest. The thickness on upper Dry Fork of Belt Creek is but 60 feet, and it is about the same back of the railway station. The quartzite base differs markedly in this respect from the section seen north of Neihart, where lower and upper sandstone layers are separated by shale. As noted below, this may possibly be concealed either by overlap or by overthrust.

The structure of the sedimentary rocks is that of a monoclinal fold, being the northern side of the broad anticline forming the range. Near the gneiss contact the dip is always steep, but the inclination lessens away from the gneiss and schist areas. On the slopes south of the Dry Fork of Belt Creek, near Barker, the schist surface slopes steeply northward, and where overlapped by the sedimentary rocks the dip is 40° northward, away from the schist contact. Near the railway station (at the mouth of Galena Creek) the ridges to the northwest show a reef of quartzite 20 feet thick whose dip is 45° to the north, and this angle of dip continues for some distance northward in the second spur west of Galena Creek. Along the trail from Barker to Neihart the basal sandstones and quartzite are seen forming a ridge running up the slope, but are wanting on the divide and are not exposed along the contact on the southern side of this divide. On upper Dry Fork of Belt Creek the basal members of the Cambrian run up to and are cut off by the Big Baldy intrusion. These observations seem to point to a sharp uplift, and indicate that the floor of crystalline schists was a slipping plane on which the Cambrian shales were shoved up and over the gneisses. Definite proof of this hypothesis seems to be afforded by the exposures along the Neihart trail. If this be true it explains the absence of the lower shales and the basal members of the quartzite and sandstone series in the exposures noted.

The Cambrian shales and interbedded limestones are seldom well exposed throughout the Barker district except over small areas, and the field work was not thorough enough to show any variations from the conditions observed at Belt Park. These rocks are seen generally along Belt Creek and about the town of Barker, and also on the summit of Otter Mountain north of the mines. Three miles east of Barker the slopes north of the Dry Fork of Belt Creek show Cambrian strata overlain by a succession of limestone beds forming cliff ledges and flat benches. Here the Devonian limestones are especially well exposed, and contain an abundant fossil fauna, from which only a small collection was brought in. To the east of this place the continuity of the strata is interrupted by the great mass of Wolf porphyry, which cuts off all the rocks earlier than the Carboniferous. A good section of the Madison limestones is, however, exposed along the wagon road up Blenkinsop Creek (the Wolf Creek road), where the characteristics of the different horizons of its formations may be studied to advantage. Between Barker Mountain and the crystalline schist area the sedimentary rocks are sharply folded in a synclinal trough, as noted in the description of that mountain.

Vicinity of Barker.—The geology immediately about the settlement of Barker is revealed by numerous exposures, for although the rocks are very generally covered by soil and vegetation, Galena Creek and Gold Run both show the rocks along their banks. Back of the railroad station the ridges west of Galena Creek show the Archean gneisses. The lower quartzite bed forming the base of the sedimentary series was not recognized here, but the succeeding reddish earths are overlain by a bed of quartzite 20 feet thick, dipping 45° E. into the hill and standing up as a bold reef or wall above the shales on either side. The soft, micaceous shales above this show an intruded sheet of chocolate-colored porphyry, also upturned and forming a broken down ledge, succeeded by grassy slopes covered with the buff débris of shales, which extend up the ridge for a half mile, until a limestone bed is seen, also upturned and weathering as a wall. The ridge above shows nearly horizontal beds of white limestones. From Belt Creek to the settlement the benches on both sides of the creek show the shales and interbedded limestones of the Barker formation, which are conformable with those seen on the ridge to the west, though the dip is less, being but 15°. These are seen to be intruded by a dark basic sheet of igneous rock (minette), 4 feet thick, near the mouth of Galena Creek and one-eighth of a mile above, or north of the railroad. A 30-foot dike of granite-porphyry, an offshoot of the Mixes Baldy mass, is seen on the west (right) side of the creek.

On the slopes west of Barker the Cambrian rocks are cut by an intrusion of porphyry. The Carter mine is situated on its contact. The shales extend several hundred feet up the slope, and are overlain conformably by the Monarch limestones. At the mouth of Gold Run the shaly limestones of the Barker formation are seen in the bluff and knoll to the north, back of the post-office. On the east side of the gulch they are seen in contact with the granite-porphyry mass (Mixes Baldy intrusion), about 600 feet from the forks of the creek. Above the settlement the wagon road to the mines follows a bench on the east side of the creek, on which no exposures are seen, but the débris is a rusty weathered, rotted porphyry, which extends to the forks of the creek. At this point the road ascends the slope and runs around the ridge separating Galena Creek from its branch, Green Creek; the ground shows occasional exposures of syenite, and careful examination shows that Galena Creek defines the boundary between a mass of coarse-grained syenite and a porphyry mass east of it, the exact contact not being determinable owing to the amount of drift and débris.

IGNEOUS ROCKS OF BARKER DISTRICT.

Igneous rocks are exposed over a large part of the Barker district, as shown by the geologic map, Pl. XLI. They constitute the most important element in the geologic structure and history of the region, and merit, therefore, a somewhat detailed account of their occurrence. They are all intrusive rocks, but vary considerably in character as well as in manner of occurrence, for which reason they will be described under the following titles: Intrusive sheets and dikes, Mixes Baldy bysmalith, Barker Mountain laccolith, Hughesville syenite stock, and Clendennin Mountain intrusives.

INTRUSIVE SHEETS AND DIKES.

The igneous rocks occurring as intrusive sheets in the sedimentary strata are conspicuous features of many parts of the district, as they resist weathering better than their inclosing strata and often form cliffs and reefs that are important elements of the topography.

Chocolate porphyry.—The most important single intrusive sheet consists of a rock whose dark-brownish weathering suggests the designation Chocolate porphyry and gives its name to a small stream cutting through it. It occurs as a sheet of varying thickness, intruded in Cambrian shales and found at nearly the same horizon in many parts of the district. It is well exposed along Dry Fork of Belt Creek east of Barker, where it forms a low cliff alongside of the stream. At the junction of Dry Fork of Belt and Galena creeks it is seen near the water level and can be traced in almost continuous exposure eastward for 6 miles up Dry Fork of Belt Creek. The thickness varies at different points, but is probably about 50 feet most of the way. In the cliff beside the wagon road the rock shows two phases. In the prevailing type it is dark-brownish colored and breaks with a square and sharply defined jointing, while its associated form is pinkish and has a spheroidal weathering. Under the microscope the two rocks are seen to be so similar that these differences are merely superficial. About a mile below Blenkinsop Creek (the stream followed by the wagon road to the Judith Basin) the Chocolate porphyry intrusive splits into three sheets. The lowest was not measured, as its base was not seen. It is separated by 60 feet of shale from a middle sheet 15 feet thick, and this is in turn separated by 12 feet of baked and indurated shale from the uppermost sheet, which is 6 feet thick. The intrusive has a dip of 15° N., conformable to that of the inclosing shales.

Farther south in the exposures revealed by Dry Fork of Belt Creek, above the point where the Judith wagon road leaves that stream, the Chocolate porphyry sheet is more irregular in its occurrence, and forms high cliffs and extensive talus heapings. Its structural relations in this locality were not determined, but the exposures actually seen seem to indicate that the pipe or conduit is located near the mouth of Gray Gulch. It forms cliffs 150 feet high, the rock resting upon baked Cambrian shale seen in a 5-foot exposure alongside the creek. The western bank of the creek shows 7 to 8 feet of baked shale overlain by 100 feet of unaltered shale extending to the summit of the bench, so that either there is a fault or the porphyry has broken through the shale here and forms an irregular intrusion, whose sharp boundary wall has been removed by the down cutting of the creek. The rocks here strike with the creek and dip to the east. The igneous rock weathers in craggy masses, is well jointed, and forms rough débris piles. The rock shows a variation in grain, one form breaking into the sharp-edged blocks typical of the Chocolate porphyry; the other form, which occurs mixed through the first in stringers and masses, is much more altered and weathers in fissile, rounded, crumbly masses. Up the stream the underlying shales pass underground and the creek cuts the Chocolate porphyry. In the park above (at Crandall Creek), as well as on the grassy ridge lying between the Big Baldy Mountain fork and the main stream, the overlying shales are seen, the remnants of a higher sheet of porphyry forming knobs on both sides of the western tributary stream and a ridge on the east. The closeness of these exposures to the margin of the Big Baldy intrusion suggests its probable connection with that mass.

The extent of the Chocolate porphyry intrusion is illustrated by its occurrence at nearly the same stratigraphic position in the slopes south of Dry Fork of Belt Creek. The limestones of the Cambrian form little hillocks, separated from the quartzite and the underlying gneiss by depressions or saddles worn in the soft shales. The porphyry is seen 250 feet above these saddles, with 200 feet of shale between the intrusive sheet and the basal quartzite. To the northwest the quartzite forms a dark, rusty, black ledge, which is readily followed along the west side of the basin cut by Ontario Creek, the dip being 30° to 40°. The Chocolate porphyry is 40 to 50 feet thick and forms the crest of a steep ridge or is seen running down the slopes on both sides of the ridge in ledges. The actual connection of this exposure with that seen on Dry Fork of Belt Creek was not traced out.

West of the junction of Galena Creek with Dry Fork of Belt Creek the Chocolate porphyry sheet is seen forming a broken-down ledge on the open and grassy shale slopes a short distance east of the railway buildings. The sheet is tilted, dipping 45° E., conformably with the basal quartzite ledges seen near by. The intrusion can be traced westward at this horizon 2 or 3 miles, but has not been recognized in this locality south of Dry Fork of Belt Creek. The Chocolate porphyry shows almost no variations in character throughout the entire extent of the exposures just noted. It is a distinctly porphyritic rock, of a gray or pale pinkish-brown color on fresh fracture, but generally covered by a brownish crust of altered rock.

Opaque white feldspars are the most conspicuous phenocrysts, though fine needle-like prisms of hornblende are far more abundant, and glistening tablets of biotite-mica are also seen. In most of the exposures these dark minerals are green, being more or less altered to chlorite, and the feldspars are decomposed and pinkish in color. Microscopic study shows the rock to be a rhyolite-porphyry.

Blenkinsop Creek intrusive sheet.—The Carboniferous limestones exposed in the ravine cut by this stream dip gently up the creek, the angle being less than 10°. They are intruded by a sheet of porphyry estimated to be 50 feet thick, whose characters are similar to those already described. The rock is gray and shows a stippling of small white feldspar phenocrysts and altered hornblende-micas in a dense pinkish-gray groundmass. The rock is a variety of rhyolite-porphyry related to the Chocolate porphyry sheet below.

Trachyte or bostonite sheet.—A sheet of light-colored rock cut by Dry Fork of Belt Creek above the Sheep Creek parks should also be noted. The rock forms a low bench, with an apron of débris in front of it. The sheet occurs in Cambrian shale but a few feet above the Flathead quartzite and is chiefly interesting because of its petrographic character. It is described in the appended paper by Professor Pirsson.

Sheet of Wolf porphyry.—The upper sheet exposed on the north side of Dry Fork of Belt Creek, east of Barker, consists of granite-porphyry of the Wolf Butte type. The sheet is regarded as an offshoot of the bysmalith mass of Mixes Baldy. It is exposed by the road cutting east of the railway terminus, and forms the grassy bench on which the cemetery is situated. By its débris and an occasional exposure it is traceable eastward as far as Blenkinsop Creek. It gradually thins out and is but 50 feet thick at the latter locality, where it appears to suddenly wedge out. Its upper surface forms a very marked sloping bench, which is 400 feet above the creek 2 miles east of Barker, but which descends westward and is traceable along the slope to Galena Creek. The interval between the base of this porphyry and the top of the Chocolate porphyry is not definitely known. It must be less than 100 feet at the eastern end of the sheet and but a few feet at the mouth of Galena Creek. The dikes observed in the shales opposite Barker are believed to be an extension of this sheet, but a mile west of Barker no trace of it was found. The rock is a somewhat altered, denser variety of the Wolf porphyry type of granite-porphyry.

Minette sheets.—Besides the Chocolate porphyry just described the shales of the district are intruded by the rocks occurring both as dikes and sheets. The most common of these is a sheet of dark trap-like rock, which has been found in almost every part of the district as an intrusive sheet. This, though only 4 to 5 feet thick, is of widespread extent, being found on Otter Mountain, at the mouth of Galena Creek, on Upper Dry Fork of Belt Creek, and filling the outcrop of the Cambrian shales for several miles up and down the course of that stream. Like the trap-dike rocks of the district, it is too much altered for positive identification, but may be classed as a minette.

Intrusive sheets of vogesite between Barker and Monarch.—Four miles west of Barker the wagon road down Dry Fork of Belt Creek is cut across the outcrop of dark basic rocks intrusive in the shales. The sheet beside the road is perhaps 35 feet thick. The rock of this exposure is clearly a lamprophyre. It is soft and altered, of a dull-gray color, with a glistening luster, and shows no phenocrysts. The exposure shows the usual concentric bowlder weathering common to such rocks. The second and upper sheet is exposed to the little drainage from Barker Mountain at this locality, where it causes a waterfall, owing to the hardening of the shales at its contact. The lower sheet is exposed alongside of the road for a mile or more eastward to another stream coming down from Barker Mountain and opposite the point where the Neihart trail crosses Dry Fork of Belt Creek. On the opposite side of Dry Fork of Belt Creek the cliff alongside of the creek shows a wall of columnar rock that is undoubtedly part of the sheets that are exposed on the north side of Dry Fork of Belt Creek. There are really two sheets, the lower 14 feet thick and the upper 25 feet thick, separated by 8 feet of Cambrian shale. The latter rocks are baked and hardened for some distance above and below each sheet and between them, the contact action being noticeable for at least 10 to 15 feet from the contact. The rock shows the same concentric weathering, spherical sheets peeling off rounded, bowlder-like masses. The rock includes fragments of the shale and also of the underlying gneiss, so it is probable that the rock came up here and spread out as a sheet in the adjacent strata. The beds dip at 20° to 25° to the south, or directly opposite to the prevailing dip of this vicinity. The shales above the upper sheet are much contracted and puckered. They show an unusual amount of alteration, secondary minerals being developed.

Dikes of Barker district.—The dikes of this district are comparatively few in number and play but a minor part in the structure of the region. They are mainly dark basic rocks, which in most exposures are too highly altered for petrographic study. Light-colored dikes also occur, but they form tongues of the Mixes Baldy mass and are therefore noted in the account of that plutonic plug. The dikes observed cut the sedimentary rocks, and in one instance the massive granular syenite near Hughesville. Their occurrence is shown upon the geologic map, but, owing to the ready decomposition and weathering of the basic rocks, it is probable that further study would add to their number.

On the eastern spur of Barker Mountain above the Kibbey divide a 12-foot dike of dark-greenish minette cuts through Carboniferous limestones, which are marmorized near its contact. Dikes of similar rock occur on the slopes north of Dry Fork of Belt Creek a mile east of Barker, and another one a half mile beyond. Similar dikes were observed 4 miles north of Barker alongside of the Monarch wagon road and near the intrusive sheets of vogesite noted in the preceding pages. A dike cutting the Hughesville syenite stock is exposed at the Wright and Edwards mine and in the mine workings. The dike is about 20 feet wide—a dark basic rock that forms one wall of the lode. The rock is dull olive-gray in color, is hard and dense, and rings under the hammer. It shows large phenocrysts of crackled, glassy, pale-brown quartz and of white or faintly brownish decomposed augite in a very dense groundmass. The rock is regarded as a kersantite.

HUGHESVILLE SYENITE STOCK.

The center of the Barker Basin is occupied by a mass of coarsely crystalline granular rock, which proves upon microscopic study to be a syenite. The area covered by it is nearly circular in outline, about a mile across, and is eroded into low ridges and hills forming the basal slopes of Barker Mountain and lying west of Galena Creek. This tract is generally smooth and rounded, showing only débris and soil, and at the present time is open, the timber having been burned or cut off. Galena Creek defines very nearly the eastern boundary of this syenite, while other portions of its contact are in part also defined by small drainage ways. The rock is granular and weathers down, so that no good natural exposures occur, and good specimens of unaltered rock can be obtained only from the various mine openings made in it. The syenite forms a "stock"—an intrusive mass breaking abruptly through all other rocks. It is nearly surrounded by Carboniferous limestones, the older rocks showing on its southern border, while to the east it adjoins a mass of porphyry. The sedimentary strata along its west contact are on edge or dip at 80° toward the syenite, but this attitude may not be the result of the intrusion. The strata are altered by contact metamorphism. The contact is generally marked by decomposed rock and the presence of many shallow prospect pits and refuse dumps. The rock is exposed on the creek banks above Hughesville. It is much jointed and altered, even the fresher material from the underground workings being cracked and seamed with pyrite films. The rock is of a grayish or rarely purplish-gray color, and shows light reflected from the flat surfaces and narrow cross sections of tabular feldspars lying in a coarsely crystalline mass dotted with the small formless masses of dark ferromagnesian minerals, mica, and hornblende.

The rock at the Barker mine is slightly finer in grain than that at the Wright and Edwards mine. The latter mine is on a shallow drain cut in the center of the ridge between Galena Creek and Green Creek, the contact being farther west. At this mine very fresh material has been extracted in driving a crosscut tunnel, but the greater part of the material on the mine dump consists of a much altered rock of a lighter greenish or white color and holding much pyrite. This alteration consists in a sericitization of the feldspars and leaching out of the dark minerals. At a shaft west of this mine the rock has been altered to a white porous material resembling loaf sugar, and consisting of quartz and sericite, the latter mineral giving it a pearly luster.

The Wright and Edwards tunnel cuts the syenite for about 200 feet before encountering a vein. The walls show the syenite to be fractured by eight or more fracture or sheeting planes, running nearly northeast and southwest, with slight reticulation by lesser cross fractures. These sheeting planes are marked by rusty iron-stained lines and a few inches of leached and altered rock.

BARKER MOUNTAIN LACCOLITH.

Barker Mountain is a broad and rounded mountain mass whose summit reaches an altitude of 8,152 feet—2,000 feet above the limestone plateau north of Monarch and 3,000 feet above Dry Fork of Belt Creek or the Kibbey Basin. The mountain slopes are well timbered, largely with pole pine. A small part of the summit is bare, as the platy débris of porphyry affords no soil or foothold for tree growth. The lower slopes north of the mountain show good exposures, and isolated ledges are seen above Barker, but the forest effectually conceals the rocks in a general view. The mountain is a dome-shaped uplift, produced by a central body of porphyry. The igneous mass has been bared by erosion, but is as yet slightly scored by gulches, and over considerable areas on the west and south slopes presents what is probably the upper surface of the laccolith. About the central core the stratified rocks may be seen dipping away on every side. The lower or under side of the laccolith is nowhere exposed, but from the observed structural relations it is probably not the flat floor of the ideal laccolith, but a curved or warped one. The horizon of intrusion is probably the Cambrian shales immediately above the solid resistant floor of Archean rocks, and the base of the laccolith probably conforms to the arching of this surface due to the uplift of the range. On the north the laccolith has broken up through the older formations and the igneous rock is seen in contact with the Madison limestones. This peculiarity is also noticed in all the other laccoliths of the range front. It is believed to be the result of a common cause, and shows that the intrusion and doming accompanied the folding of the range. The rocks generally show no recognizable evidence of movement or shearing since consolidation. The uplifting and arching of the laccolith so close to the borders of the Archean rocks result in a very sharp folding of the stratified rocks. On the south side of Dry Fork of Belt Creek the strata are seen dipping steeply away from the gneissic area, and this dip extends northward across the creek on the lower slopes of the mountain. At higher elevations the dip suddenly flattens, and still higher is reversed, so that on the southern side of the mountain the Cambrian shales which form the benches and lower slopes along Dry Fork of Belt Creek pass under the Monarch and Madison limestones, but are exposed again above these rocks, between them and the porphyry area. Near the railroad terminus the beds dip northward, or toward Barker Mountain, at 45°, and the second spur west of Galena Creek shows the Monarch limestones thus tilted. In the mountain slopes opposite the town limestone cliffs are seen, appearing nearly horizontal when seen from the town, though really dipping gently toward Barker Mountain and forming the edge of a basin fold whose central mass of Carboniferous limestones forms the eastern spurs of the mountain.

The curving or warping of the stratified rocks about the porphyry mass is especially well shown along the course of a small creek, whose channel is parallel to and follows the western contact of the porphyry. The drainage is cut in the soft shales, but on the western bank the limestone beds are seen rising with the creek and curving with it around the mountain flank. Here and there little patches of porphyry—remnants of an intruded sheet—are seen capping the limestones. The dip is about 30° away from the mountain. The porphyry surface is readily distinguished from the sedimentary areas, as it is covered by a dense thicket of lodgepole pine and down timber, in marked contrast to the open or sparsely timbered sedimentary areas. The western slopes of the mountain are smooth and rounded, and form a great conchoidal surface, like part of a huge sphere. The surface is slightly indented by shallow drains, but the general rounding is very marked. It is evidently the surface of the laccolith, from which the shale cover has been and is being stripped, and shows nearly the original face of the intruded mass. At the lower borders of the porphyry area the thinly bedded limestones which occur in the shales of the Barker formation are seen in imbricated outcrops sheathing the porphyry, like the scales of the cup of an acorn. The porphyry contact is not regular along the southern slopes and does not run uniformly about the slopes. On the middle south spur the contact extends down to 5,700 feet, the Cambrian shales, which

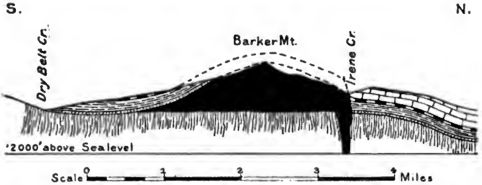


FIG. 43.—North-south cross section through Barker Mountain.

are much baked, dipping steeply away from the porphyry surface, but flattening out to 20° a hundred yards from it.

The eastern spur of the mountain running down to the Kibbey road shows a sharp synclinal folding where the beds upturned by the Barker and Otter Mountain laccoliths meet. For several hundred feet above the divide the Carboniferous limestones dip westward, or into the mountains. At 400 feet above the road there is an abrupt and sharp change, the inclination being outward, or away from Barker Mountain, the dip being 45°. The rocks are cut by a 12-foot dike of greenish rock (minette), trending to the syenite area at Hughesville. The rocks adjacent to the dike are marmorized, this effect being the more noticeable since there is no appreciable alteration or baking of the strata near the laccolith contact. The little creek emptying into Dry Fork of Belt Creek below the railroad terminus, heads in the saddle, 1,100 feet above the Kibbey divide, marking the contact between the laccolith porphyry and the blue Carboniferous limestones, the gulch being eroded along the contact. The beds dip 50° E. and strike nearly north and south, the dip being up the lower thinly bedded limestones of the basal portion of the Madison limestone series. The porphyry slide rock extends down 400 feet below the summit on the eastern spur. A detached bare knob, 100 feet lower than the main summit of the mountain, is not shown on the map. The porphyry near the contact is dense, whitish gray, and shows small feldspar phenocrysts.

Barker porphyry.—The main mass of the mountain is formed of a finely crystalline or granular rock of gray color, dotted with large white feldspars, and peppered with green hornblende and biotite. It is a rock recalling many dacites, and from its appearance alone might be called a mica-hornblende-dacite-porphyry. Its chemical composition and detailed microscopic study show it to be a variety of granite-porphyry, and it is designated the Barker porphyry. As already noted, the other laccolithic rocks are like it or near it in character. Very close to the contact with the sedimentary rocks the Barker porphyry is dense and slate-like, splitting into thin, irregular plates parallel to the plane of contact. These plates, upon weathering, break into small angular or sherdy fragments, owing to a network of minute joints. In places it is a dense felsitic rock, carrying scattered quartz phenocrysts and showing no visible hornblende or mica, and is thus a rhyolite porphyry.

OTTER MOUNTAIN LACCOLITH AND INTRUSIVE SHEETS OF CLENDENNIN MOUNTAIN.

The mountain slopes inclosing the Barker Basin on the north are part of a mountain mass jutting into the open country of the Judith Basin, and owing its relief to a laccolithic uplift and doming of the strata. The laccolith of igneous rock is revealed by the sharply incised drainage on the western side of Otter Mountain, and although the dome has not been dissected far enough to expose it elsewhere, the overlying cover of sediments shows by its structure the nature of the uplift. This is the more noticeable since the synclinal basin between this mountain mass and Taylor Peak shows a trough of quadrant shales, while the Cambrian rocks which are seen on its summit are 2,500 feet above the Cretaceous rocks on its western and northern sides, showing a lifting of at least 5,000 feet produced by the intrusion. On the summit the beds are nearly flat or dip gently to the northeast. On the southeast flanks the dip is 20° to 30° away from the center of the mountain. To the west the dip changes, and there is a local crumpling of the shales. The summit shows Cambrian rocks, the alternation of shale and limestone producing tables, cliffs, and slopes, which are parked or open grassy slopes with patches of timber. A minette dike, 4 feet wide, and trending N. 26° E., crosses the summit. The laccolith is intruded in the Cambrian rocks as usual, and between it and the gneiss. The mass must be large and thick, as may be judged by the size of the arch and the vertical extent of the uplift.

The little creek draining an amphitheater cut in the north side of Otter Mountain shows an excellent section of the strata overlying the Madison limestones. The beds dip away from the mountain at 50°. The contact was not visited, but the stream drift shows an abundance of quartzite of light flesh color, pink, and gray, running into a fine conglomerate with pebbles one-fourth of an inch to 4 inches across. Extensive talus slopes of porphyry are seen on the higher slopes, and the stream drift contains an abundance of the denser contact forms of this porphyry, and of the dense hornstones produced by the metamorphism of the Cambrian shales. The structure is that of a breached anticline, and is very evident when the mountain is seen from the open country west of it, as the strata are seen wrapped about the porphyry core. The common form of the porphyry is a dense lavender-colored rock, dotted with occasional phenocrysts of white orthoclase, and sprinkled with minute black needles and scales of biotite and hornblende. It is a variety of rhyolite-porphyry. A very dense felsitic rock also occurs, which probably represents a contact form of the rock. It is a pale, faintly greenish-gray rock, dotted with very dark purple spots. Small feldspars are the only phenocrysts seen.

Like most laccolithic intrusions the Otter Mountain mass is accompanied by, or bordered by, sheets intrusive in the sedimentary cover. These sheets are seen near the contact on the west side, but the examination was not thorough enough to prove their presence on other sides. The remnants of sheets which cap Crown Butte and vicinity may come from this or from the Barker Mountain mass.

The Clendennin Mountain mass is a separate elevation, whose southern slopes are covered by heapings of porphyry slide rock, which conceals all rock in place. From what is seen in the mines and on the gaps at the head of the basin, it is evident that the mountain is carved out of the southward-dipping beds forming the south side of the laccolith anticline. The beds are penetrated by two or more thick sheets, locally thickened and perhaps forming small laccoliths. The sheets have been cut across in the erosion of the basin, and the rock thus forms the talus heapings seen here. These slopes shut in the basin above Hughesville and extend westward nearly to the Kibbey divide and eastward to the gap north of Mixes Baldy. The creek heading in the latter gap defines the boundary between it and the mass of Wolf porphyry to the south, a road to the Moulton and Tiger mines being built along the base of the talus. The porphyry débris contains some limestone and shale. The mines are located on a vein in the porphyry near the limestone contact.

The rock is mapped as a syenite-porphyry. It is a fine-grained, dense rock of a light-pink and gray color. It shows no porphyritic quartz, and has an andesitic look, but proves upon microscopic examination to be a variety of rhyolite-porphyry. It might perhaps be classed as a quartz-mica-porphyry, as it shows phenocrysts of orthoclase, plagioclase, and biotite in a groundmass of quartz and feldspar, so that although it was grouped with the syenite-porphyries in mapping, it is more closely related to the Barker porphyry. The border facies of the Otter Mountain laccolith is a rhyolite-porphyry.

The rocks near the Tiger mine are sheared, showing that they have suffered movement since consolidation. This is believed to be the result of local thrust produced by the intrusion of the Mixes Baldy mass, which is, on this and other evidence, believed to be later and to cut off this rock abruptly.

MIXES BALDY INTRUSIVE MASS.

The eastern part of the Barker Basin, together with Mixes Baldy and the peaks south of it, is cut in a mass of Wolf porphyry. This great body, which is 1½ miles wide and 2½ long, and forms several mountain peaks, consists of a rock which is very uniform in appearance throughout the whole extent of the body. It is a dull rusty gray, with very prominent phenocrysts of smoky-colored quartz and larger ones of white feldspar. It is distinctly porphyritic, the quartz grains giving it a general resemblance to a conglomerate. The variations in texture occur near the margin of the mass and bear a definite relation to the contact plane, or the thickness of the offshoots from the parent body. This uniformity of character indicates what the field observations prove, that the mass is a single one, formed of a single body of magma injected at one time and by a single act. The rock is crumbly when weathered and does not form conspicuous exposures, and the slopes are generally smooth and rounded. On the mountain summits the rock is exposed, but is more or less altered, and the rocks crumble beneath the hammer. The surface is covered with the coarse pearly sand into which the rock disintegrates, and in which the large feldspars, often an inch or so long, form conspicuous features. The rock is a typical granite-porphyry, like that of Wolf Butte. The quartz phenocrysts are large, but cracked; the groundmass appears granular and like a fine granite.

Gold Run basin.—The mountains south of Mixes Baldy form the rim of the amphitheaters cut in the mass by Gold Run. The summit is flat and gently round, open, and parked with groves of wind-swept pines at the edge of the slopes. A few craggy exposures which occur on the edges of the summit are particularly noticeable, as the big feldspar phenocrysts give the rock a bizarre appearance. More commonly the summit shows only the sand resulting from the weathering of the rock. The amphitheater or basin of Gold Run is also cut in this rock. It is an extensive basin, with very steep slopes on the east, and separated by a big densely wooded ridge from the Tiger mine branch of Galena Creek. The basin is generally wooded, save in the center, where a sloping grassy bench suggests a change of rock, though it proves to be also cut in the porphyry. In the basin the creek cuts rather deeply into the rock, and about a mile above Barker crosses a massive exposure of the granite-porphyry, 200 to 300 feet high, cutting a deep trench partly through it and completing the descent in a very fine little waterfall. The outcrops here are especially good and very picturesque, as the Wolf porphyry weathers into massive crags, which on the right-hand side run toward the hill in smooth slopes dotted with castle-like and hoodoo forms of erosion. Some prospecting has been done on leads in this rock just above the falls, as well as farther up the creek, the ores being galena. Similar prospects were observed in the rock a mile east of Hughesville.

The granite-porphyry mass is an intrusion that has broken through the previously tilted limestones and other sedimentary strata, subsequent to the formation of the Otter Mountain and Barker Mountain laccoliths. The Mixes Baldy mass is not a laccolith. It is to be classed as either a bysmalith or a stock. The sedimentary rocks about its borders are, for a short distance from the contact, very steeply upturned on the eastern and northeastern flanks, but on the three other sides of the mass show little if any disturbance by the intrusion. There is very little contact metamorphism, and this occurs only at the immediate contact. The relation of the mass to the surrounding rocks is shown on the geologic map (Pl. XLI).

Galena Creek dike.—An offshoot of the mass, or its border, is exposed along the north slopes of Dry Fork of Belt Creek, east of Galena Creek, where it occurs above Cambrian shales, and is covered in turn by other strata belonging to the same age. The wagon road is cut across it a short distance east of the railway terminus. From here eastward the sheet thins out, and is but 50 feet thick 1½ miles east of Barker, where it ends as a thin wedge in the Cambrian shale. This sheet is separated from the main mass of Wolf prophyry by a round-topped ridge thinly capped by shale and limestone. This mass is shown on the map as connecting with the main mass around the west end of this ridge. Owing to the drift and soil, it is impossible to establish this beyond all doubt. A 20-foot dike of this rock is seen cutting the Cambrian shales exposed on the west side of Galena Creek, one-eighth of a mile above the railroad, and this is believed to be a western extension of the intrusion just noted. Back of Barker (i. e., northeast) a similar dike of porphyry, which is of the Neihart type, is seen cutting the limestones and shale and trending southward to the town. The rock contains in it various fragments of shale limestone and a basic igneous rock. The contact of the main mass is seen east of the town of Barker, on the south side of Gold Run, 300 feet from the creek.

Contact relations.—At the borders of the intrusion it is in contact with strata of various ages, lying at various altitudes. Near Barker the porphyry cuts across the strata of Cambrian age. Followed eastward the contact is with successively higher and younger strata, until 2 miles east of Barker the upper strata of the Madison limestones are cut by it. On the flanks of Mixes Baldy the contact is with Cambrian again. On the north it adjoins the intruded sheet rocks of Clendennin Mountain, and the syenite mass of Hughesville farther down.

The strata at the border of the intrusion are apparently unaffected by it on the south. Near Barker the beds dip toward the intrusive mass at 15°, and 1½ miles east of Barker the mountain slopes also show limestone benches dipping at 10° toward the igneous contact. About the head of Arrow Creek (or Lonetree Park) the limestone strata are steeply upturned, dipping at 70° away from the contact (strike N. 10° W.) 1½ miles southeast of Mixes Baldy, this altitude prevailing to the gap north of that peak, where the dip is 80° to the southeast, into the mountain. The last locality is the only place where marked alteration of the contact rocks was observed, the limestones being marmorized and the shale indurated, but no contact minerals were seen.

The divide above the Tiger mine is cut in limestone, the contact with the Wolf porphyry being 100 feet above the saddle on the south side. The beds strike N. 45° E. and dip at 70° to 90° W., into the mountain, and form a wedge-shaped block, extending down the gulch toward the Tiger mine to a point 500 feet below the saddle. The trail above this mine is, however, cut across slopes of Wolf porphyry to a point 100 feet below the saddle, and from there to the summit it crosses the micaceous porphyry of Clendennin Mountain.

MONARCH DISTRICT.

The region adjacent to the town of Monarch, together with Thunder Mountain, Pilgrim Creek Valley, and Tiger Butte, is conveniently described under this heading.

GENERAL FEATURES.

The general geologic structure of this district is simple. The stratified rocks have a general northward dip, away from the Archean center of the range. This structure is disturbed by the dome-shaped uplifts of Tiger Butte and Thunder Mountain, due to laccolithic intrusions of igneous rock.

The topography is varied. The most noticeable features are the deep canyons, presenting precipitous cliffs with almost ideal exposures of the sedimentary rocks.[1] Where the canyons are cut across the strike of the beds both sides of the gorge show good exposures, but the largest canyon, that of Belt Creek, shows receding slopes on the south and steep cliffs on the north, owing to the prevailing northward dip of the strata. The two mountain masses of Tiger Butte and Thunder Mountain dominate the topography, and are landmarks visible for great distances across the open country north of the mountains. The valleys of Logging, Pilgrim, and Tenderfoot creeks show the usual narrow gorges cut in the massive limestone series, with broader basin-like valleys where the softer Cambrian shales prevail. The region is well wooded south of Belt Creek, but the character and relative abundance of the timber varies with the exposure and also with the nature of the soil and rock; it is most abundant on northern slopes and on porphyry areas. Up to the present time no productive mines have been found in the district, and Monarch is the only settlement. Prospecting has shown the presence of ore deposits on the flank of Thunder Mountain and Tiger Butte, and also in the valley of Pilgrim Creek. The iron ores of Thunder Mountain are described in the account of the ore deposits of the range. The other deposits are silver and gold ores, of which small quantities have been packed out over the horseback trails and shipped to the smelter at Great Falls. Limestone is quarried near the mouth of Logging Creek, and there is a sawmill near the head of the stream. With the exception of a few acres of arable land near Monarch, the district is not susceptible of agricultural development. The high limestone plateau north of Belt Creek is, however, a very fertile and productive wheat area.

MONARCH CLIFFS.

For several miles from Monarch up and down Belt Creek and the Dry Fork the slopes to the south are more or less wooded and show no prominent exposures, while to the north a line of cliffs rises in grand exposure several hundred feet high. These cliffs of white limestone are largely stained by the orange color and reddish material from less pure layers, and might be fittingly called the Orange Cliffs. Nowhere in the region are better and more imposing exposures of the Carboniferous rocks. At Monarch the brown limestones, which take their name from the town, form the valley floor, and the cliffs northwest of the railroad station show only the Carboniferous, the contact with the Monarch limestones being hidden by débris. The cliffs seen in Pl. XLIII, *A*, show, however, unusually good exposures of the impure argillaceous limestones forming the lowest member of the Carboniferous, which are so generally characterized by the presence of silicified fossils. The rocks are dark-blue and dull straw-colored, earthy limestones when fresh and unaltered, but the weathered surfaces and shaly fragments into which the rocks break are of a buff or rosy-pink color, and frequently show the fossils weathered out in relief on exposed surfaces. These rocks are capped by the massive block-jointed beds of limestone which are so prominent in the Orange Cliffs and give them the banded effect, as the more massive beds alternate with shaly layers. The following section was measured at the base of the cliffs immediately north of the station. (See Pl. XLIII, *A*.) These cliffs are not everywhere persistent to the top of the plateau, but show a general escarpment of 300 to 400 feet, with branches and cliffs above, broken occasionally by coulées or deep and narrow gulches tributary to Belt Creek.

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[1] See Davis, Tenth Census, Vol. XIV, p. 708.

Dry Belt section, Orange Cliffs of Monarch.

	Feet.
Castle limestone:	
Massive Carboniferous limestones; heavy bedded, rough surfaced; forms crags; holds round lenticular masses of chert up to 12 inches in diameter	400
Limestone; platy and fissile. (Fossils 30 feet above the base of this bed)	100
Limestone; massive. (Fossils just beneath this bed)	10
Limestone, shaly	200
Limestone, less shaly than above	
(The three beds last described with underlying fissile limestone form bold red bluffs and walls.)	
Woodhurst limestone:	
White limestone bed, weathering as ribbon ledge above second line of buttresses	135
Second buttress line. Thin bedded limestone, carrying fossils	
Limestone; dark gray, weathering buff; shows argillaceous lines; weathers down frequently	
Limestone, massive, 6 feet	
Limestone; very dark gray, alternating with light-gray rocks; forms first buttress line	
Limestone; gray, compact, pure, in beds 5 to 10 feet thick; forms base of massive cliffs	
Limestone; impure and shaly; carries silicified fossils	30
Shaly limestone; light buff-colored, with one-half foot layers of harder limestone carrying chert lenses 10 inches across and 3 inches thick	35
Paine shale:	
Fissile limestones, in 6 to 10 inch layers; dense in texture, showing cross-bedding structure	5
Banded limestones forming cliff face. Light-buff and gray limestones in 6 to 12 inch layers, of rather hard, compact texture, carrying chert lenses of 3 inches by one-half inch, alternating with earthy shaly limestone in 3 to 6 inch bands, usually of a light-buff to dark blue-gray color, but varying to pink when weathered. The layers are inconstant and grade into one another horizontally	45
Monarch limestone:	
No exposure.	
Brown limestones.	

South of Monarch the eastern side of Belt Creek shows a line of cliffs whose limestone beds dip at a gentle angle downstream. Near

Uhls Station, about 8 miles above Monarch, the Archean gneisses are seen overlain by sandstones and shales which are intruded by a great sheet of augite-syenite-porphyry, from 70 to 100 or more feet thick. This rock forms the steep walls of the canyon, and passes underground at Uhls, where it forms the rocky bed of the creek. At this place the cliffs to the east show an excellent section of the lower part of the sedimentary series. Owing to local landslips, the shale formation above the basal sandstone series is not well exposed, but it can not be very different from that of Keegan Butte, only a short distance to the southeast, where it was measured in company with Mr. C. D. Walcott. The following section represents the complete series from the Archean to the middle part of the Carboniferous.

Section of beds exposed north of Belt Creek, 8 miles south of Monarch.

		Feet.
Castle limestone:		
Massive bed of limestone, heavily bedded, in places reddish colored.		
Woodhurst limestone:		
Fissile limestones, or calcareous shale, generally weathering down		50?
Limestone; forms persistent bluff or reef on slopes, gray		25?
Limestone, not shaly; upper 100 feet carrying silicified fossils		150
Shales and shaly, dark-gray limestones. Fossils 648 of table, p. 292		175
Paine shale:		
Limestone; cream colored, splintery fragments	5	10
Conglomerate; gray brown	3	
Limestone; cream colored	2	
Threeforks shale:		
Limestone; fissile, pink to light-buff colored shaly beds, believed to represent shales of Devonian		35
Jefferson limestone:		
Limestone; rough, granular, brown (coffee colored)		15
Limestone; white, massive		5
Limestone; granular, brown		5
Limestone; light brown, splintery		5
Limestone; light brown, sandy and granular, pitted, with large cavities (6 inches), in part due to limestone forms. Emits a fetid odor when crushed with a hammer; weathers in steep cliffs		15
Limestone, yellow, forming ledge with black-streaked face, but elsewhere weathering down to a steep slope		50
Limestone; forms biggest and most prominent ledge of mountain side, irregularly bedded, lilac-gray, roundish weathering, and resembles mottled limestone of Gallatin times. Ledge undercut, and forms cavernous recesses		55
Yogo limestone:		
Limestones, thinly bedded (2 to 6 inches), alternating with 5-inch strata showing no lamination lines. Cherty, very dense, dove-gray, not crystalline, breaking with block jointing and into prisms; weathers as cliffs.		60
Limestones, alternately thick and thin bedded		15
Limestones, gray, weathering buff, thinly bedded (6 to 24 inches); forms pediment of cliff		25
Limestone, thinly bedded, gray. Beneath big cliffs		25
Limestone, thinly bedded. Beneath big cliffs		8
Dry Creek shale:		
Shale or shaly red limestone		5

	Feet.
Dry Creek shale—Continued.	
Shaly limestone, light blue-green and thinly bedded white limestones	15
Shales, red, earthy, and not laminated like micaceous shale of lower part of Cambrian. Shales are crumbly and of bright dark-red or purple color	40
Limestone, granular or saccharoidal, yellow and red limestone, with earthy portions irregularly distributed through bed	12
Alternating thinly bedded limestone and conglomerate, and green fissile laminated shales and shaly limestones	15
Pilgrim limestone:	
Alternating beds of thinly bedded limestone or conglomerate and shaly limestone	20
Limestone, fissile or shaly, argillaceous	20
Limestone, conglomerate	2
Limestone, thin bedded, carrying a little conglomerate. (Bed is baked by intrusive mass.)	35
Volcanic sheet	40
Limestones, thin bedded (one-fourth to one-half inch), alternating with micaceous shaly limestones and conglomerate. Exposure looks like a pile of boards	20
Park shale:	
Shales, micaceous, leafy, black. Obscured by landslips; thickness given from estimate based on aneroid readings	600
Meagher limestones:	
Limestones, flaggy, not well exposed. Thickness on Keegan Butte is 80 feet	110
Wolsey shale:	
Shales, leafy, grayish green, micaceous	125
Flathead sandstone:	
Quartzite, white	1½
Sandstone, rusty, rotten	5
Sandstone, flaggy, white or buff-colored	15
Sandstone, fissile, rusty colored, varying to purplish shale	30
Sandstone, massive	1
Quartzite, flaggy	6
Quartzite, vitreous, and massive; neither well bedded nor fissile	60
Augite-syenite, intrusive	70
Sandstones, black, and at times ferruginous. Quarzite, white and pink	25-50

THUNDER MOUNTAIN.

Thunder Mountain is the name given to the high mountain northwest of Belt Park. It is composed of a great mass of igneous rock, some 4 miles broad. The outline of the mountain is rather flat, but lacks the smooth dome shape of Barker and Baldy mountains. The flanks are wooded, but the summit is generally bare and covered by platy débris. The igneous mass is not a typical laccolith, for, as described by Lindgren,[1] "it does not disturb the sedimentary rocks to a very great extent; its only action has generally been to turn up, perhaps even reverse, the edge of the nearly horizontal surrounding strata for a distance of 1,000 or 2,000 feet." In general, the rocks about the borders of the intrusion dip sharply away from it. Fig. 44, copied from Lindgren, shows the general relations of the sedimentary rocks to the intrusion, as seen along the contacts 590 feet above the creek.

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[1] Tenth Census, Vol. XV, p. 720.

This place was also visited by the writer. The limestones belong to the Jefferson formation and show but little alteration, although so near the igneous rock. The latter, near the contact, shows a pronounced platy parting, which causes it to break into small bits. The usual deposits of iron ore occur at the contact. The attitude of the rocks shown by the figure is true only near the contact, for if this divide ridge be followed southward, toward the low wooded summit at the head of Tillinghast and Tenderfoot creeks, it is found that the rocks, instead of dipping away from Thunder Mountain at from 3° to 5°, flatten out in a short distance and change to a dip of 20° to the north, or toward Thunder Mountain. The section thus exposed in following the ridge or divide southward embraces the normal succession of formations seen throughout the region.

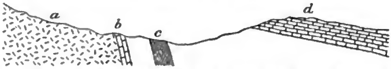

FIG. 44.—Contact between igneous rocks and limestone on south side of Thunder Mountain. *a*, dacite; *b*, red-weathering limestone (Silurian); *c*, bluish shale; *d*, heavy limestone (Carboniferous).

In these upturned beds south of Thunder Mountain eight sheets of porphyry occur, conformably intruded in the limestones and shales. These intrusions consist mainly of hornblendic porphyries allied to that of Thunder Mountain, but minettes and augite-minettes also occur, the rocks being generally too altered for definite recognition. At the north end of the mountain the trail from Monarch to Pilgrim Creek follows along the contact, which is well exposed at several places.

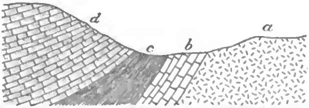

FIG. 45.—Upturned beds at north end of Thunder Mountain. *a*, dacite; *b*, heavy limestone; *c*, black shale; *d*, sandy limestone (Devonian).

Fig. 45, by Lindgren, shows the prevailing structural relations of the igneous rock and the surrounding sediments on the northern side of the mountain. On this side the drainages cut deeply into the limestones and head in shallow gullies scored in the igneous rock. The spurs show a sag or depression between the igneous rock and the limestones, due to the presence of the Cambrian shales between the limestone and porphyry. This sag affords easy traveling and is the route followed by the trail. The shales show little, if any, appreciable metamorphism, and it is only at Iron Creek, where bodies of iron ore occur along the igneous contact, that there is any metamorphism. Here the lower shales are exposed, and they are indurated to dense hornstones. It may be noted, however, that the eruptive débris is so extensive and slides down the slopes so freely that it conceals the actual contact plane, and it is not improbable that similar contacts might prevail on other spurs. The rocks at the Iron mine dip away from the mountain at 40°, but flatten rapidly in a few hundred yards, and dip about 20° on limestone knobs above the shale sags, this lessening to 6° at Belt Creek. It is apparent that these beds are uplifted by the igneous rock, since they are seen in Tillinghast Creek, the flat stream bottom being cut in them. The Jefferson limestones show 200 feet above the creek at its forks, where the beds dip at 3° down the creek.

At the point where the trail descends from the shoulder of Thunder Mountain to Pilgrim Creek a mining prospect was observed, 1,000 feet above Pilgrim Creek. The brown Jefferson limestones appear 350 feet above the valley shale. These beds probably form a sharp trough face, for the Cambrian shales are found above and below them. The limestones are underlain by an intrusive sheet of porphyry along the red shale horizon. Along the trail the dip is 20° down the mountain side, at a place perhaps 600 feet above Pilgrim Creek.

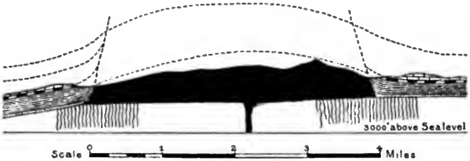

FIG. 46.—North-south section across Thunder Mountain.

The west slope of the mountain shows the same sharp infold as observed alongside the Pilgrim Creek trail. The igneous rock has pushed up the sediments so sharply as to form a trough, which forms cliffs, seen on an escarpment line above the landslide slopes of shale. The exposures, however, were not visited.

The eastern side of the mountain was not visited. Seen from the south, it shows talus slopes, which are undoubtedly of porphyry, with limestone beds below, dipping away from the mountain at 30°. Lindgren[1] noted "black, somewhat metamorphosed Silurian (Jefferson?) limestone, dipping at 15° toward the eruptive." The valley of Tillinghast Creek is cut in Cambrian shale, and forms fertile benches occupied by several ranches and watered by numerous springs.

The Thunder Mountain intrusion is not a typical laccolith and does not arch up the strata about it, as plainly shown by fig. 46, as well as those already given. Lindgren says,[2] "The whole can be compared to nothing but an enormous plug driven up through the sediments." It seems to be an irregular laccolith, corresponding perhaps to the type of intrusion to which the name of bysmalith has been applied by Iddings, and its structural relations are noted later in the chapter on dynamic geology of the mountains.

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[1] Tenth Census, Vol. XV, p. 721.

[2] Ibid., p. 720.

The igneous rock is a variety of the Barker porphyry type of granite-porphyry. Its resemblance to the rock of Barker Mountain is mentioned by Lindgren, who gives a description of it under the name of hornblende-dacite. The rock is described in the report appended to this paper, and needs no further comment here.

TENDERFOOT MOUNTAIN.

Between the head waters of Tenderfoot and Tillinghast creeks, and west of Belt Park, there is a low, rounded, densely timbered mountain mass to which this name is given. It is a broad mass of igneous rock, from which the strata incline away at gentle angles in each direction. It is so densely wooded that good exposures are rather rare, and as only the northern side was visited the outline given on the map is merely approximate. The rock is similar to that of Thunder Mountain, and undoubtedly occurs as a laccolith intruded between the gneiss complex and the Cambrian formations.

VALLEYS OF PILGRIM AND TENDERFOOT CREEKS.

Pilgrim Creek and Tenderfoot Creek valleys are broad mountain depressions cut in the soft Cambrian shales. They present similar geologic conditions, and at both places there are mining prospects from which small amounts of ore have been extracted and packed out. The valleys are formed by streams cutting into rocks whose general dip is in the direction of the stream. In the lower course both creeks cut deep and narrow canyons through the heavily bedded limestones, but as the dip of the beds is downstream the upper course is sunk through these rocks, and broader valleys are eroded in the soft micaceous shales of the Barker formation. The lower benches and slopes are parked by open groves of the stately yellow pine (*Pinus ponderosa*). The upper slopes were once densely timbered with the lodgepole pine, but are now burned, and only a forest of poles remains. The harder rocks are well exposed in the lower canyons and the escarpments which overlook the valleys, but the soft shales are rarely seen except along the narrow and deeply cut creek channel.

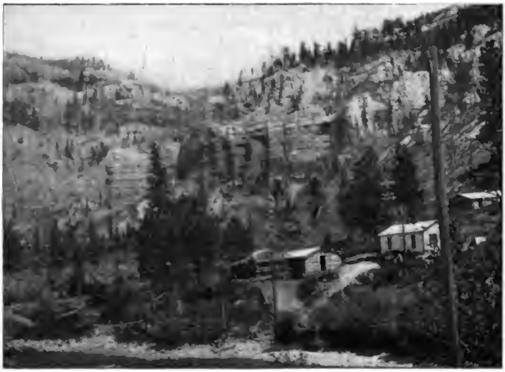
In both Pilgrim and Tenderfoot creeks the shale valley is bordered by cliffs of limestones, the ledges running along the slope until the dip brings them down to the creek level, and they close in the valley. The valley slopes are often disturbed by landslides. The conditions are especially favorable for this, as the massively bedded limestones rest on soft shales, whose downward dip facilitates slipping when the shales become soft and slippery by saturation. This is especially noticeable about the flanks of Thunder Mountain.

About the head waters of the streams the limestones extend down the spurs leading into the valleys, as the dip is downstream.

The only section measured in this part of the range was a partial section of the cliffs west of Pilgrim Creek, opposite the point where the trail comes down from Thunder Mountain. The creek banks at this point show good exposures of the Park shales of the Cambrian, in which there are abundant fossil remains, identified for me by Mr. Walcott, as mentioned in the first part of this paper. The cliffs to the west of these exposures show a perfect section, but only the following partial section was made:

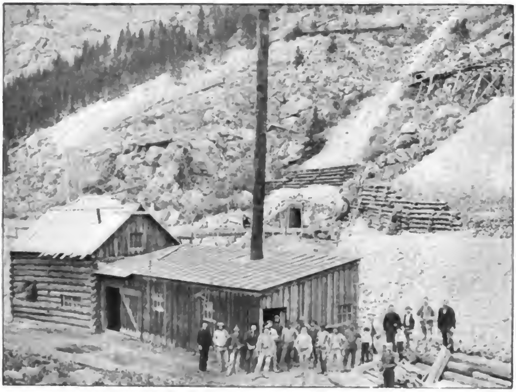
Section on Pilgrim Creek, northwest of Thunder Mountain.

	Feet.
Orange cliffs:	
Limestones, thin bedded (beds 3 to 6 feet).	
Shaly beds	50
Limestones, block jointed, red, brownish weathering, in beds 3 to 4 feet thick.	
Limestone in broken ledges, chocolate colored.	
Poorly exposed beds of light chocolate-colored limestones.	
Limestone, forming prominent, heavy, black-jointed ledge, showing no striping.	
Chocolate beds:	
Alternating beds of thin chocolate-brown limestones and buff-colored, argillaceous beds, the latter not of persistent thickness.	
Jefferson formation:	
Chocolate-colored limestone, with lighter cream-colored parallel lines striping face of exposure.	
Yogo limestone:	
Persistent ledge of heavy, massive limestone, brown gray, and lighter than rocks above.	
Massively bedded, brownish-gray limestone.	
Base of big cliffs and bluff.	
Dry Creek shale:	
Impure, very argillaceous, and sandy limestone, weathering light buff and showing fucoid markings, sun cracks, and argillaceous partings	10
Olive-gray shale	8
Limestone; straw colored, shaly, thinly bedded, impure	4
Red and green shale	20
Limestone, gray green to olive brown, weathering light pink or buff; arenaceous, with granular texture	3
Gray-green shale	5
Red shales, and straw-colored earthy or magnesian limestone	30–35
Pilgrim limestone:	
Sandstone	5
Poor exposure; limestone varying to a conglomerate and shale	20
Park shale:	
Conglomerate of limestone pebbles	355
Soft micaceous shales	
Thinly bedded, impure limestone, with argillaceous matter, mottled, and with characteristic weathering	
Soft micaceous shales	
Ribbon beds or banded limestone, carrying fossils	
Thinly, irregularly bedded limestone in layers, 2 inches to 4 inches thick, separated by layers of soft, micaceous, argillaceous shale one-fourth inch to one-half inch thick	



A. CLIFFS OF LIMESTONE NEAR LOGGING CREEK STATION, BELT CREEK.

Paine shale, capped by Woodhurst limestone



B. FLORENCE MINE, NEIHART.

Showing massive gneiss outcrops and gully cut in outcrop of vein

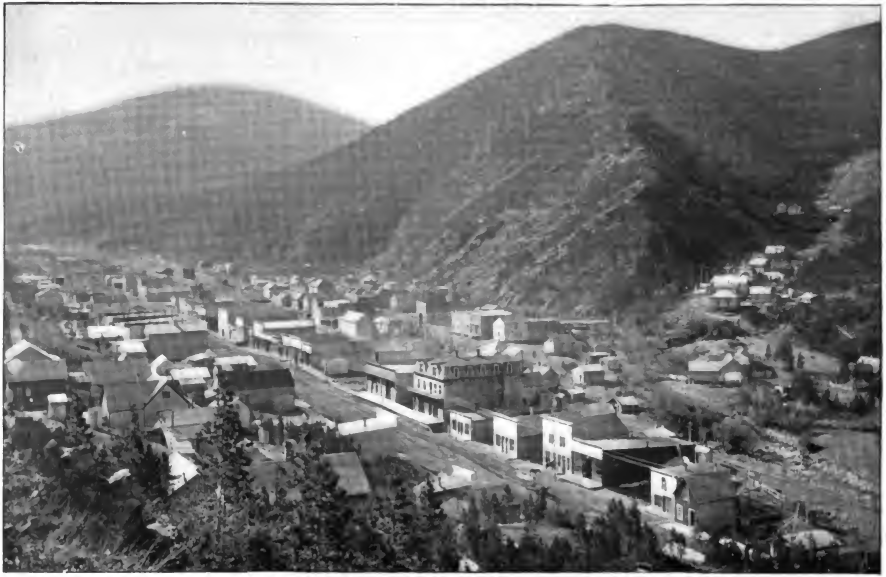
In Pilgrim Creek Valley, as is commonly the case in the northern part of the Little Belt Range, the shales of the Cambrian formation are intruded by sheets of igneous rock. Intrusive sheets were noted in the Cambrian limestones at the head of Pilgrim and Tenderfoot creeks, and in most instances prospectors have sunk shallow pits along the contacts looking for ore, but there are no extensive explorations at either place. Both localities are at present accessible by trail only, but wagon roads of easy grade could be cheaply built if developments warranted it. In Pilgrim Creek, immediately above the main forks of the stream, two such sheets are seen intruded in shales, the silvery gray intrusives forming a narrow bench that defines the outcrop of the sheet for a mile or so along the slope. The mineral prospects seen in this vicinity are in connection with the upper sheet. The creek exposes a thickness of about 200 feet of shale here, but the shale is indurated and hardened by contact metamorphism, and as the intrusive sheets have not produced this alteration there is reason to believe that the main mass of the Thunder Mountain core lies not far below, though its nearest edge is seen a half mile distant and 600 feet above on the slopes to the east.

SLUICEBOX CANYON.

Between Tiger Butte and the high limestone plateau that extends eastward to Barker Mountain there is a broad and well-defined valley cut in the Carboniferous limestone. The rocks possess a general northerly dip of about 6°, but there are many small local flexures and faults. In this broad, rather shallow valley Belt Creek has cut a very narrow trench, from 50 to 150 feet deep, with vertical and overhanging walls. The creek flows in a succession of deep and rapid reaches of great beauty. The narrow gorge has been christened the Sluice-boxes, or Sluicebox Canyon, and from the railroad, which follows the old valley level above the canyon, the view is superb. The general appearance is well shown in the illustration (Pl. XLV).

TIGER BUTTE.

This rather sharp and prominent butte is caused by an asymmetric or irregular laccolith. The summit and sides are formed of limestones, dipping away from the mountain on all sides, and arching over its top. The general horizon of intrusion is not definitely known, but it is probably the Cambrian. On the north the igneous rock has broken through to the higher beds and is in contact with the Jurassic, and at this place it has been bared by erosion and is exposed to view. The rock is similar in character to that of the other laccoliths of the region, and belongs to what has been designated the Barker type of granite-porphyry. It weathers with the usual massively platy parting, is much shattered by joints and weathering, and forms extensive talus heaps. There are the usual silver prospects about the contact, but though rich samples of ore are said to come from the deposits, no workable bodies of ore have as yet been brought to light. The butte lies some little distance in front and away from the general margin of the range, so that the laccolithic doming of the strata is very prominent. Only a part of the butte comes within the limits of the accompanying map (Pl. XXXVI). Logging Creek has cut its valley between the range and the butte, and a small stream defines its western borders. The latter shows no igneous rocks in its gravels, so that although not visited, it is believed that no igneous rocks occur on the western side.



NEIHART, MONTANA; SEEN FROM THE NORTH, LOOKING UP BELT CREEK.

The first gulch seen on the right of the picture is Johnson Gulch, and beyond is the cut of O'Brien Creek.

CHAPTER VI.

DESCRIPTIVE GEOLOGY OF THE NEIHART DISTRICT.

LOCATION AND GENERAL FEATURES.

The principal settlement of the Little Belt Mountains lies in the center of the range, not far distant from the geographic center of the State. It is situated on the head waters of Belt Creek, in the bottom of the deep mountain valley of that stream, with the sharp point of Neihart Baldy overlooking the town, and the high plateaus of Belt Park and its neighbors surrounding it on the west. (See Pl. LI.) The general situation of the town is shown in the map of the district (fig. 52, p. 403). The location is accessible by wagon road from White Sulphur Springs and the Judith Basin, and is the terminus of a branch line of the Great Northern Railway running from Great Falls, from which place it is 65 miles distant. The town owes its origin and existence to the ore deposits of the surrounding district.

The Neihart district, embracing the drainage tributary to Belt Creek in the immediate vicinity of the town of Neihart, presents scenery and geologic structure quite different from those of the parts of the range already described. The town is situated near the southern end of an area of metamorphic rocks, which constitute the central core of the range and are believed to be of Archean age. These are overlain by stratified rocks which dip away from the Archean contact at steep angles to the south and at relatively low angles to the north. The Archean rocks themselves are cut by eruptives of several different ages.

ARCHEAN GNEISSES AND SCHISTS.

The Archean rocks are well banded, have a prevailing dip or plane of schistosity of 45° to the south, and show no traces of sedimentary origin.

The ridge at Johnson Gulch shows a rough crest, formed of harder, dark-red, feldspathic schists, but no massive weathering gneisses are seen on the east side of the creek until the gully defining the shoulder of Neihart Mountain (or Neihart Baldy) is reached, where the massive rocks near the Broadwater mine are seen, with strike and dip of schistosity planes conformable with those found farther north. Viewed in a general way, the gneisses show very distinct and well-marked divisions of color and lithologic habit. Red feldspar-gneiss, white or gray feldspar-gneiss, black mica-schist or amphibolite, and the more schistose rocks appear to be persistent divisions. To a certain extent such distinctions can be made in a rough way, and they prove to be very important distinctions in the economy of the ore deposits, but when studied in the attempt to map the boundaries of such rocks they are found to grade into one another without order or system. Moreover, the very intricate and indented intrusion of the peculiar Pinto diorite has modified the schists near its contact, and though somewhat gneissoid yet uniform in character, its surface is less varied than the gneiss.

At only a few localities was the igneous character of the schists recognized. Some 300 feet above the town, on the road from the Broadwater mine, a foliated rhyolite-porphyry was found. A similar rock, but leached and altered, occurs in the Queen mine. At the upper end of the Broadwater road a very fissile rhyolite-porphyry-schist was obtained. It is a pale cream-colored rock, weathering a buff or straw color. It is very fissile, splitting into slaty débris, which conceals its outcrop. This is due to an abundance of sericite flakes developed along the folia. The edges of the fragments show a very decided flow structure, with quartz phenocrysts drawn out into lenticules. The rock is a sheared rhyolite-porphyry. Another form is much less schistose, and is a distinctly porphyritic rock. Large oval masses, one-fourth to three-fourths of an inch long, of sheared and drawn-out granules of red quartz, and smaller dull-white feldspars, appear in a dark-gray or greenish-black groundmass; the rock is a sheared rhyolite-porphyry. With these exceptions the rocks do not show their derivation to the naked eye.

The rocks south of the town, and between it and the Broadwater workings, are schistose and fissile, breaking readily along the folia and seldom showing massive outcrops (see Pl. XXXVII, *A*). North of the town, on both sides of Belt Creek, the rocks are gneisses, in which along Rock Creek a diorite is irregularly intruded. There is, however, no transition between these schistose and gneissic forms, and no evidence showing their character to be due to metamorphism produced by the diorite. The most notable varieties can be distinguished as gray feldspar-gneisses, red feldspar-gneisses, and amphibolite-gneisses.

The gray gneisses show wide variations in texture, color, and foliation. In general, they are coarsely crystalline, with mica folia separating a coarsely granular mixture of quartz and feldspar. The red gneiss forms fairly well-defined bands, which, like the folia, are lenticular in shape. The rock occurs as patches and streaks in mica-gneisses along Rock Creek and north of the town. Typical specimens from the Moulton mine are evenly granular medium-grained rocks, showing a streaking of dark-green chlorite. The rock consists of a mixture of pinkish feldspar and quartz. A red gneiss from the mine workings—the 400-foot level west—is a very dense and finely granular rock, broken by small joints into diamond-shaped rhombs. The red gneiss encountered in the Queen workings is coarsely granular, and forms patches separated by black mica-schist, and is associated with a gray mica-gneiss. The altered quartz-porphyry-gneiss from this mine is like that of the Broadwater, but can not be mapped as separate from the inclosing gneisses. A black mica-gneiss consists of a biotite and quartz, with white lenses of quartz and feldspar.

The amphibolites also vary from coarse to fine-grained textures. The coarser rocks are usually evenly granular and show little foliation, except on dark reddish-gray weathered surfaces, where the feldspar shows as pinkish material and the rock is distinctly streaked. The rock breaks with a sharply angular fracture into thin flakes. The commoner variety seen in the mine workings is a very tough rock with rounded fracture. It is a finely and evenly granular amphibolite, but slightly schistose to the eye, and consists of a felty mass of interlocked hornblende needles. This rock is seen along Rock Creek above the Moulton, and in the Florence and other mine workings.

The gneisses of Carpenter Creek form uniform and rather smooth but steep slopes, having a few rock outcrops of reddish gneiss pillars, but covered by fine débris supporting a dense growth of small pine, so that in a general view the country appears smooth, and shows the topography typical of simple erosion of a homogeneous material. The grassy tops of the hills are smooth and bare of outcrops; the canyon walls rough, with picturesque masses. Their aspect at the mouth of Carpenter Creek is shown in Pl. LXV, *B*.

On Snow Creek the porphyry of Poverty Mountain ends a short distance above where the wagon road to the Cornucopia and Benton mines leaves the main creek. The prophyry is in contact with a hard and dense, blocky, gray gneiss banded with amphibolite. This gneiss prevails for several miles up Snow Creek, changing to a red feldspathic gneiss where the trail crosses the slopes west of the creek. The slopes between Snow Creek and the Cornucopia show alternate belts of black amphibolite and red feldspathoid gneiss dipping north. The Cornucopia is on a bench cut in the ridge between the forks of Snow Creek, in black micaceous gneiss, but the Pinto diorite forms a bench to the north, below the shaft house. Follow ingthe road from the Cornucopia to Neihart, porphyry is found at 8,000 feet, forming a spur down to 7,700 feet, where the black gneiss outcrops.

OLDER IGNEOUS ROCKS.

PINTO DIORITE.

The gneiss series is intruded by a large and very irregular body of diorite which has been designated the Pinto diorite, from its spotted appearance. This rock occurs in a continuous body on the ridges between Rock Pinto and Carpenter creeks, is cut across by the canyon of Belt Creek below Carpenter Creek, and forms the gateway of Harley Creek. It was traced up the last-named creek one-half mile, beyond which the exposure was not followed, owing to the dense timber and débris covering the slopes. Isolated exposures of this rock were also found at the extreme head of Carpenter Creek west of Long Baldy Mountain, at the Broadwater mine, and near the Cornucopia and Barker mines of Snow Creek. At the last localities it is possible that there is a surface connection with the main body, but it was not determined. In the very narrow and steep gulch near the head of Carpenter Creek, Pinto diorite occurs intrusive in black amphibolitic gneiss, at 8,000 feet, or 300 feet below the top of the black amphibolite just below the summit. The exposure at this place is small and the rock contains many included fragments of gneiss, a common feature of the borders of the mass, though at this locality the denser contact facies of the rock was not recognized. It is cut by a minette dike, trending to the east. There is reason to believe that all these exposures are part of a single great body—a batholith, and that the several masses now exposed connect at an unknown depth.

The rock has a striking appearance. Photographs of a hand specimen are shown in Pl. LXXIII, *A*. The rock consists of roundish, pale-green, white, or pink feldspar masses or aggregates, one-half to 1 inch across, closely packed, with the interspaces filled with schistose hornblende. In the freshest material obtained from underground workings the feldspar is pale green in color. The porphyritic appearance produced by these feldspar groups is most striking on weathered surfaces, where they are reddish in color and stand out in relief. The rock is very uniform in habit and character throughout the district. In most cases there is no change in grain at the contact, but the southern borders of the main body exposed along Rock Creek above the Moulton mine show a very marked contact facies, in which the feldspars are thinly tabular, and are arranged in a fluidal structure, which is very striking on a weathered surface. At this locality, also, both the denser contact form and the coarse-grained rock are cut by aplitic dikes, which are regarded as connected with the intrusion, the aplite being a fine-grained granite, much mashed. These dikes are often only an inch or two across and are accompanied by dark seams. They are seen only near the contact.

The contact between the Pinto diorite and the schists is an extremely irregular one. Not only is it indented by projecting wedges and tongues of diorite in the schist and of sharp and irregular wedges of the schist in the diorite, but many masses of schist are included in the diorite. The relation of the two rocks is complicated by late dynamic forces, causing the development of a gneissoid structure in the diorite.

The Pinto diorite has a more massive weathering than the schist. This is especially noticeable on the sharp ridges dividing the drainage of Rock and Snow creeks. At this place the diorite forms rough, craggy masses, shown in Pl. XLIX, *B*. The rock breaks into great blocks, 2 to 10 feet across. It shows a distinctly spotted character on freshly fractured surfaces, but where long exposed to the weather is reddish and largely overgrown with lichens. These exposures, like those nearer the town (above the Moulton mine), hold stringy masses of schist and are streaked with occasional seams of aplite. The included fragments of schist and gneiss do not show any melting on their edges, nor the development of contact minerals.

YOUNGER IGNEOUS ROCKS.

RHYOLITE-PORPHYRY OF ROCK CREEK.

On the narrow divide between Snow Creek and Rock Creek (the gulch just back of the town) the Pinto diorite and gneisses are cut by a mass of porphyry, whose débris is scattered over the surface and is seen in several shallow prospect pits, though its boundaries could not be determined. The rock is not schistose, but shows a fracturing approaching flowage. It is a pale-green rock, with abundant phenocrysts of dark-gray quartz 2 mm. in diameter. This quartz shows doubly terminated pyramidal crystals, and the grains commonly project above the fracture planes of the rock, though others fracture with the rock. The groundmass is extremely dense and felsitic, and is of a grayish-green color. The rock is much altered and the former feldspar phenocrysts are now spots of yellowish earthy matter, probably sericite and kaolin. The rock is a rhyolite-porphyry (quartz-porphyry of older nomenclature), but it differs in both texture and appearance from the Carpenter Creek type of that rock.

NEIHART PORPHYRY.

The rhyolite-porphyry distinguished by this name occurs as dikes and large intrusive bodies cutting the Pinto diorite and gneisses. It forms the dikes seen in the workings of the Galt, Ingersoll, Benton, and other mines, and is exposed on the surface north of Belt Creek. It also occurs in irregularly intrusive bodies in the slopes adjacent to Snow, Carpenter, and Mackay creeks, where various ore bodies have been found in it and mines located. Its outcrops are seldom massive, as the rock is crackled by a network of fine joints, and breaks into small angular débris, which covers the slopes, and under favorable conditions forms extensive débris slides, such as those seen on Poverty Mountain, as the hill between Snow and Carpenter creeks is called. Throughout the different exposures the rock is fairly constant in habit, though it varies somewhat in appearance, owing mainly to the alteration that has occurred near ore bodies, or the changes produced by weathering. The rock is a normal rhyolite- (quartz-) porphyry showing rather small phenocrysts of quartz 1 to 2 mm. across, scattered through a very dense felsitic-looking groundmass, which is white in some cases, but in the vicinity of the ore deposits it is pale green. Irregular-shaped masses of rusty earthy material occurring in some specimens represent phenocrysts wholly decayed—probably biotite. The altered rock of the ore deposits is impregnated with pyrite grains, and is often brecciated.

The fine rhomboidal or diamond-shaped fractures which crack the rock cause it to break readily into angular débris on weathering. This rock is seen at the Galt, IXL, and Eureka mines, and at these localities the fragments often show a black surface, due to oxidation of pyrite. The Mackay Creek mass, in which the ores of that area have been found, is intrusive in the gray and red schists, and is found on both sides of this creek from the head to the mouth. It extends across to Carpenter Creek and forms the sharp ridge between that and Mackay Creek. On the opposite side the extent of the porphyry is not accurately known. A short distance (estimated at half a mile) below the mouth of Mackay Creek it is not seen, and gneisses are exposed.

The ridge between Snow and Carpenter creeks shows granite-porphyry at its very end, but the Neihart porphyry of Poverty Mountain appears one-fourth mile above the junction of the streams, as noted. The Neihart porphyry occurs on the spur below the Cornucopia mine on the ridge east of the Benton mine, being exposed alongside of the Cornucopia road at 6,900 feet, with black gneiss below it. The porphyry extends across the slopes to the Benton workings, showing at the point where the road swings around to the south, where it descends to Benton Gulch, and the rock is cut by a crosscut level from the Benton to the Flora vein. No surface connection between this and the mass at the IXL mine was found.

West of the Snow Creek Basin porphyry outcrops 350 feet below the Rock Creek divide, just below the IXL mine, and is 200 feet wide on top of the ridge, and abuts against gneisses. To the east the schists extend to Snow Creek, but the Neihart porphyry forms the crest of the spur and connects with the Poverty Mountain mass near the junction of Snow and Carpenter creeks.

CARPENTER CREEK PORPHYRY.

The canyon wall north of Carpenter Creek shows a ledge of light-colored rock running along the wall for several miles. It forms a vertical cliff 50 to 60 feet in height, whose base is about 300 feet above the creek. The ledge does not continue west along Carpenter Creek to Belt Creek, but as the crest of the ridge becomes lower it crosses the spur and appears on Belt Creek a half mile or more below Harley Creek; and here it is very plainly seen to be an inclined dike or sheet dipping north at 45°. It is here 30 to 35 feet thick, and cuts through the Pinto diorite. It shows a contact band 3 to 5 feet wide at top and bottom, and the rock holds many fragments of schist and gneiss torn from the fissure walls. On the cliff seen north of Carpenter Creek this contact is very apparent, owing to its darker color and different weathering, due to a denser texture.

The reef can be traced as far as the mouth of Snow Creek, where it is lost on the smooth slopes to the north. An exposure of it was found on the doab[1] ridge between Snow and Carpenter creeks, at the extreme end of the spur. The rock is light gray in color, and thinly spotted with crystals of pale-pink orthoclase an inch or less across, with smaller light-colored feldspars between. These lie in a gray groundmass sprinkled with black dots of biotite. The rock is not schistose, and is apparently of later age than the diorite.

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[1] Triangular space between two streams at their junction; see Century Dictionary.

TRAP DIKES (MINETTES).

Besides the rocks already mentioned as intrusions in the gneiss complex of the Neihart district, dikes of minette also occur at the Galt and Ingersoll mines and at the head of Snow Creek. They are regarded as due to the igneous activity of the Yogo Peak center, since they possess the composition and characters peculiar to the rocks of that locality. They are soft and easily weathered rocks, which are seldom exposed except under the most favorable conditions. It is possible that they are more common about Neihart than at present supposed, since they would be concealed by gneissic débris on the surface, and in the altered condition prevailing about the veins in most mine workings would not be readily recognizable. They are an important bit of evidence, however, since their occurrence shows that the ore deposits which cut them are of later age, and therefore certainly post-Jurassic, and probably Tertiary.

SEDIMENTARY AREAS.

QUARTZITE RIM ROCK.

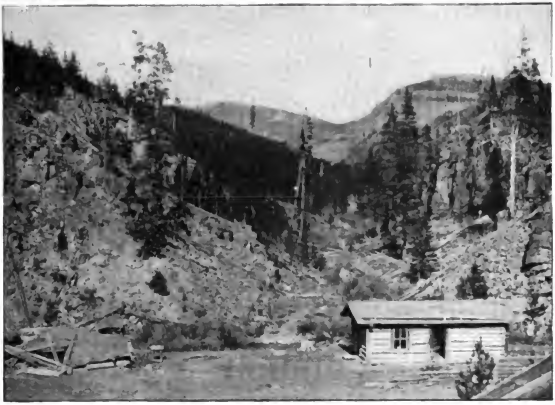
The mountain slopes above Neihart show massively bedded quartzites capping Neihart and Long Baldy mountains (Pl. LII, *A*), and the same beds are seen as a rim rock running along the edge of the plateau west of the town. The latter outcrops are nearly horizontal, but followed southward the beds are seen to dip in that direction, as they do on Long Baldy Mountain, and to be overlain by a thickness of 4,000 feet of gray slaty rocks. The exposed edges of the quartzite beds are seen running down the slopes east of Belt Creek, and 2 miles above the town the creek has cut a very strikingly picturesque canyon through these rocks (see Pl. XXXVIII, *B*). Above this canyon the slaty series composing the various formations of the Belt terrane are seen for several miles up Belt Creek and its several branches. The detailed section of these beds has already been given in the description of the terrane. The thickness varies greatly, however, at different localities. On the O'Brien Creek road it is not over 1,000 feet, probably less, while on Sawmill Creek it is 4,500 feet, and on Chamberlain and Belt creeks a little less.

The slaty rock beds of the formation are cut by sheets and dikes of intrusive rocks, which alter the strata, and are frequently prospected for ores. The intrusions are relatively small and part of the fringe of sheets and dikes surrounding the Yogo center.

BELT CREEK PARKS.

Along the stage road up Sawmill Creek, as well as on the old O'Brien Creek road, the slaty Belt rocks are seen overlain by reddish and yellow cross-bedded sandstones, the basal beds of Cambrian formations. These rocks are well indurated, and as they are overlain by soft shales that weather readily, the sandstones form extensive grass-covered plateau areas lying between the creek valleys. This is rendered more effective by the intrusion of a thick sheet of prophyry in the fissile beds just above the base of the formation, a sheet whose characteristic cliffs and talus slopes are shown in Pl. LII, *B*. These sheets outline extensive plateau areas between Belt and Sawmill creeks. The areas of porphyry and quartzite débris are very generally densely timbered with lodgepole pine, as shown in Pl. XXXVII, *B*. They are thus in strong contrast to the open grassy or sparsely timbered areas where shales cover the surface. This is noticed not only on the plateau but along Belt Creek on the Yogo trail. These plateau levels are the most characteristic topographic features of the Neihart district. They are all due to the resistant nature of the quartzite or sandstone beds. Near Neihart it is the Neihart quartzite that determines the level area; south of Neihart it is the Flathead quartzite. In going south from Neihart along Belt Creek or any of its branches the stratified rocks are seen to dip to the south. On the summit of Long Baldy the dip is 20° to 22°. Along Sawmill Creek it is at first 14°, but increases to 20°, which prevails until the sharp twist in the road is reached, where the Cambrian Flathead sandstones have a much gentler dip, changing to 2° to 3° on the grassy plateau levels. An angular unconformity exists between the two series, but it is much less marked than these dips indicate. The Cambrian shales are soft, easily intruded rocks, and in them the igneous intrusions are abundant, and the intruded sheets thickest. The shale formations attain a thickness of about 1,200 feet near the divide between Belt Creek and the neighboring drainage basins, and, as elsewhere, are separated by several formations of limestone. Nowhere within the actual limits of the Neihart district, as defined by the drainage basin of Belt Creek, are more recent stratified rocks exposed.

North of Neihart the crystalline schists form a hilly country, deeply trenched, yet with smooth and generally rounded slopes. West of Belt Creek the plateau area known as Belt Park is, like the smaller areas to the south, formed by nearly level beds of indurated sandstones resting upon the schists. The fissile impure sandstones found interbedded with the harder shales of this locality hold fossils of Cambrian age, and the two buttes which rise above the park are formed of shales and limestone whose fossils prove to be Cambrian types. The southern limit of the park, where it is cut off by Harley Creek, shows the Cambrian resting directly upon the crystalline schists with no intervening beds. Similar conditions prevail all about the western and northern



A. NEIHART QUARTZITES OVERLAIN BY SHALE FORMATIONS OF BELT TERRANE, LOOKING UP SMALL DRAINAGE ON SOUTH SLOPE OF NEIHART MOUNTAIN FROM JUNCTION OF BELT AND SAWMILL CREEKS.

Shale slopes seen in distance.

B. INTRUSIVE PORPHYRY SHEET AND CHARACTERISTIC TALUS SLOPE, SAWMILL CREEK ROAD, SOUTHEAST OF NEIHART.

margins of the Archean area, no Belt rocks occurring north of an east-west line through Long Baldy Mountain at Neihart.

HEAD-WATER VALLEY OF BELT CREEK.

Belt Creek above Neihart Canyon flows through a mountain valley, whose width and character vary with the nature of the rocks. The lower park, cut in Belt shales, extends for a mile above Chamberlain Creek. To the north the slopes have been densely wooded, the forest being now largely cut or burned over. The slopes are steep up to the cliff fronts of the terraces formed by porphyry sheets. The normal sequence of the Belt rocks is seen in occasional exposures along the creek. The shales prevail to Chamberlain Creek, where they are broken by an intrusive sheet of porphyry. Above Chamberlain Creek the blue Newland limestones appear, in beds 3 to 5 feet thick, with interbedded shales. The limestones are either shaly or, in more massive beds, the rock breaks into splintery fragments. They weather buff, with square jointing, break into cubical blocks, and contain carbonaceous markings and calcite streakings. They are succeeded by black shales, extending up the creek until the low ledges of dark-colored Cambrian quartzite appear. The beds dip upstream at low angles until the divide at the head of Running Wolf is reached, where the dip is westward, or down Belt Creek.

The sedimentary rocks encountered on Chamberlain Creek show the same beds. The channel is cut in shale for 2 miles above its mouth, and above here in the Neihart quartzite. A sheet of porphyry intruded in the sandstones of this formation covers with its drift a large part of the mountain side to the north. The intrusion is a sheet perhaps 300 feet thick, tapering to the west, and regarded as an offshoot of Big Baldy. Cambrian beds here conformably dip upstream.

Belt Creek above the quartzite exposures shows a wider valley, where it is cut in the overlying soft shales, and a beautiful park occupies its center. Up the Yogo trail few exposures are seen until the crest of the divide is reached, for dense but open woods prevail until the steep and open or parked higher slopes are reached, where the soil is thin and occasional low exposures of green shale and knotty surfaced, thinly bedded limestones are seen, with one intrusive sheet exposed 725 feet below the top. The ridge to the north of the trail, a lateral spur of the divide, shows better exposures along its crest, and the soft shales are seen to be intruded by a dozen or more sheets of igneous rock. These are of two kinds. The first is the light-colored rhyolite-syenite-porphyry, which, on account of its hardness, forms benches.

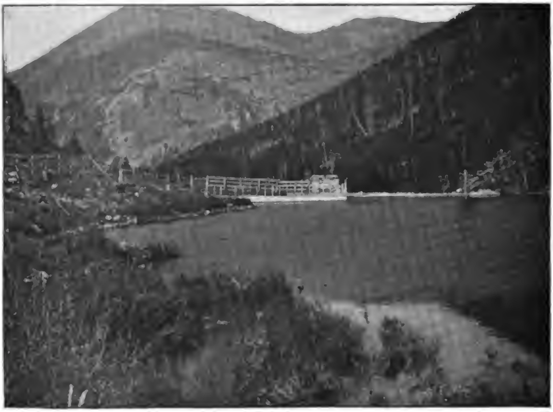
INTRUDED SHEETS AT HEAD OF BELT CREEK.

These intruded sheets are syenite-porphyries, which vary somewhat in appearance according as the sheet is thick or thin. They are chocolate or purplish-gray rocks, characterized by abundant phenocrysts of dull-white feldspars and black or greenish hornblende needles, and sometimes mica scales. These dark-colored minerals are altered to chlorite and rusty limonite spots in the weathered forms. The sheets break with a platy fracture, and their débris covers the slopes and obscures the lower contact. The rocks of the thicker sheets possess a strong resemblance to the syenite porphyry of the laccolith end of the east end of the Yogo stock. The sheet forming the crest where the Yogo trail descends to Belt Creek differs from the common type of porphyry forming the intrusive sheets. It occurs on the east crest, intruded in shaly beds that dip 5° W., and swings across the ridge to the ridge to the west as lower beds appear in going north from the trail. The rock is a pale-greenish, very dense, hard, platy-looking rhyolite-porphyry, showing infrequent rectangular sections of pinkish orthoclase up to one-fourth inch across, and a few scattered grains of a clear, glassy quartz. The weathered surface is buff colored and shows a minute pitting, revealing a banded or flow structure.

The west slopes of this divide ridge contain numerous intruded sheets in the Cambrian shales, eight being counted on the spur visited, running down between two head-water branches of Belt Creek. The sheets vary from a few feet to 75 feet in thickness, and weather in step-like benches that terminate in rocky cliffs. The rocks are syenite-porphyries, but include two sheets of minette. The two thickest sheets, one 75 feet thick 400 feet below the top, and the other nearly 100 feet thick at the base of the slope, have baked and altered the rocks for 10 feet from the contact. The lower 600 feet shows six intruded sheets. Although there is little doubt that these sheets, like those so generally observed in the district, are continuous for considerable distances, only two of them were seen on the slopes crossed by the Yogo trail, owing probably to soil and débris, but there is no reason to doubt that they would be found if carefully looked for in essentially the same horizons on all the spurs leading down into Belt and Wolf creeks.

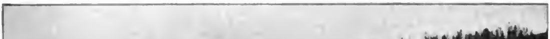
OUTLINE OF GEOLOGIC HISTORY OF NEIHART DISTRICT.

The crystalline schists are the oldest rocks of the mountains, and constitute the central core or nucleus, about which the later stratified rocks have been folded. The bedded rocks show that the Neihart region has been the site of dynamic disturbance from the very earliest geologic time. The cliffs of Long Baldy Mountain and the rim rock of the plateau to the west are formed by sedimentary strata deposited along the shore of an Algonkian sea, in whose waters the very oldest forms of life known to the world existed, and remains of which were recently discovered near Neihart. The region of Belt Park and Hoover Creek, north of Neihart, was a land area, the shore being near the present site of the town. This location was along the "hinge line" between the northern continental land and the gradually sinking sea to the south, in which 4,500 feet of strata were laid down. The lines



A. O'BRIEN CREEK RESERVOIR, WITH NEIHART MOUNTAIN IN DISTANCE.

The saddle in top of mountain is the head of Narrowgauge Gulch, and separates Neihart Baldy from Long Baldy.



B. OUTCROPS OF GNEISS NEAR OLD SILVER SMELTER OF HUDSON MINING COMPANY, BELT CREEK, BELOW CARPENTER CREEK, NEIHART.

of weakness developed at this time may have been intensified by those later oscillations of level to which the entire region was subjected throughout later geologic epochs, but no definite data as to their effect upon this region are obtainable.

It is probably to later igneous activity that the fissuring of the rocks is due. These represent at least two, perhaps three, periods of dynamic disturbance, but their age is not known, for they do not cut the sedimentary strata. The most important intrusion was that of the magma forming the Pinto diorite. This rock is found penetrating the schists in every direction and over an extensive area. Its contacts appear to be without order or arrangement, and over the district distinguished by mineral veins the observed facts indicate that it underlies even a larger area than is indicated by its surface exposures. That its intrusion shattered the schists is shown by the numerous included fragments in it. In places it shows endomorphic contact phenomena, but more generally the observed facts indicate a thorough heating of the adjacent rocks and a slow cooling of its mass. That it is later than the schists is shown by the structure of the included fragments, and that it is earlier than the last dynamic movements producing schistosity is shown by its gneissoid structure.

This Pinto diorite is of unknown age. It may be pre-Algonkian, but its occurrence near the base of the quartzite beds of Long Baldy Mountain and the absence of any fragments of it in the conglomerates of those strata are opposed to this hypothesis; its gneissoid structure would accord with this idea, since the Algonkian rocks are but slightly metamorphosed. Still later igneous forces ruptured the rocks, in whose crevices dikes of porphyry were injected, or formed irregularly intrusive masses. These rocks cut the diorite as well as the schists, and although sheared, they are not gneissoid or schistose. The period of their intrusion is not known.

A third period of energetic igneous activity accompanied the uplift of the range, or directly followed it, and the igneous rocks, which were sent out as sheets and dikes from various centers of disturbance, occur in the stratified rocks surrounding the Archean area of Neihart, and are sometimes found in it. The period of vein formation and ore deposition either accompanied or followed these igneous intrusions. The precise geologic age of the ore deposits is unknown, because they are found only in the older rocks of the region. On the summit of Long Baldy the ores occur in the quartzite overlying the gneiss, but nowhere else do they cut stratified rocks. Inferentially the deposits are believed to be post-Cretaceous.

CHAPTER VII.

GENERAL GEOLOGY.

HISTORY OF REGION AS INTERPRETED FROM SEDIMENTARY ROCKS.

The sedimentary rocks of the region show that the same general conditions prevailed in the Little Belt region as in the rest of the eastern part of the Rocky Mountain area of the State. The stratigraphic sections are very similar and show the same formations recognized throughout the geologic province. There is, however, one feature of especial importance shown in this section, namely, the overlap of the Cambrian beds from the Algonkian rocks of the southern part of the mountains to the Archean gneisses of the northern.

The Archean rocks are, so far as recognized, wholly of igneous origin, and may be supposed here as elsewhere to represent the downward crystallization of the original crust of the earth. These rocks were already metamorphosed to gneisses and schists of the same character seen to-day when the earliest known sedimentary rocks of the region, the Neihart quartzites, were deposited, for occasional pebbles of red and gray gneiss are found in the latter.

The Neihart quartzites were laid down upon what appears to be a very uniform surface. The lower beds consist of clean quartz sand, but silty material appears in the higher beds and in all the rest of the Belt terrane, which attains a thickness of at least several thousand feet in the southern part of the range, and of 10,000 to 12,000 in the Big Belt Range. These beds are shallow-water deposits. During the period in which the rocks of the Belt terrane were deposited the northern part of the Little Belt area was probably above water, for no Belt rocks are found there, and the beds immediately overlying the gneiss contain no material indicating the former existence of such rocks in the northern part of the range. Of the conditions prevailing through this part of Algonkian time there is little knowledge other than that which may be deduced from the character of the beds themselves. These show a cycle of deposition, with slowly deepening sea, followed by gradual emergence. The only forms of life yet discovered are those described by Walcott.[1]

After the formation of the Belt beds the whole region was uplifted. There is not only an entire absence of Lower Cambrian throughout this and the neighboring ranges of central Montana, but the succeeding beds consist of assorted sands whose material varies in character from place to place with the nature of the underlying rock. The belt formations were extensively eroded in this interval, and as a consequence the Flathead sandstones, which constitute the basal beds of the Middle Cambrian, rest upon different formations at different places. Angular unconformity between the Belt and Cambrian rocks has been seen, but it is seldom very noticeable in exposures. The overlap of the beds is itself convincing proof of unconformity. The plane of contact on which the Cambrian rests is a very uniform one, and is especially so when it is the Archean. This is seen in the canyon wall along Belt Creek and Belt Park, as well as in lower Sheep Creek. This plane surface presents the characters of a plane of marine erosion, or shore-line cutting. Crosby[1] has recently called attention to the widespread extent of this feature. Pebbles of Belt rocks in the basal beds of the Flathead, where the latter formation rests upon the Algonkian terrane, and of gneisses and schists over Archean areas, show the erosion caused by a spreading sea margin. These Flathead sandstones represent a general subsidence of this region in common with the rest of the eastern mountain region of the State. The level plane of contact was apparently formed as the sea cut back and wore down the land during a gradual submergence. The overlying beds show, in the shales, impure limestones, and intraformational conglomerates, as well as by the fossil remains, that the conditions prevailing were those that are known to have prevailed commonly in Cambrian time over large parts of the continent.[2]

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[1] Fossiliferous pre-Cambrian terranes: Bull. Geol. Soc. America, Vol. X, 1899, p. 199.

So far as at present known, there are no beds of either Upper Cambrian or Silurian age in this region, the fossil remains from adjoining beds holding Middle Cambrian and Devonian forms, respectively. It is assumed, therefore, that the region was a land area during the Upper Cambrian and Silurian periods.

The Devonian period is represented by arenaceous limestones whose fossil remains are mostly corals. No unconformity is recognizable between these beds and the succeeding layers of the Carboniferous, though a bed of red sands was observed in one exposure and may indicate estuarine conditions.

The Carboniferous period was one of slowly deepening, followed by shallowing, seas. The rocks contain abundant fossil remains, which are wholly of Lower Carboniferous types, and the well-defined subdivisions recognized in the Mississippi Valley and the States east of it have not been distinguished. The lowest beds are impure, argillaceous, shaly limestones, and the fossils contained in them are shallow-water forms. The middle and greater part of the rocks of this age are, however, quite pure limestones, more rarely dolomites, and the life is such as to indicate relatively deep water. The close of the period was, however, one of elevation, and there is an abrupt change to very shallow-water and estuarine areas in which red sands and gypsum deposits were formed. These conditions were followed by a gentle depression, with the formation of green shales alternating with limestones, whose fauna also indicates shallow and muddy waters.

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[1] W. C. Crosby, Bull. Geol. Soc. America, Vol. X, 1899, pp. 141-164.

[2] Walcott, Cambrian rocks of Pennsylvania: Bull. U. S. Geol. Survey No. 134; and Correlation Papers—Cambrian: Bull. U. S. Geol Survey No. 81.

No definite break or unconformity is in general recognizable between the topmost beds of the Carboniferous and those of the succeeding marine Jurassic. On the southern flanks of the range the highest beds of the Carboniferous show a fauna somewhat different from that prevailing elsewhere, and their fossils are found within 2 feet of Jurassic fossils. There is, moreover, some evidence of an erosion interval in the varying thickness and absence of certain beds of the Quadrant group of the Upper Carboniferous. The succeeding Jurassic period was at first one of quiet waters covering the entire area, but the limestones formed in this time are succeeded by beach sands holding shell remains evidently broken by wave action, showing a gradual elevation of the land, that resulted in the rapid deposition of sands which are barren of life.

The succeeding Mesozoic rocks do not form any part of the mountain area, but it is necessary for a comprehension of the conditions determining the uplift of the range to understand the fact that the sediments of Cretaceous age all show a thickening, with a great increase of sands and clays near the mountain front. The conditions indicate quite clearly that there was a general and widespread uplift in early Cretaceous time, accompanied by the formation of marsh lands and fresh-water lakes, while volcanic eruptions breaking forth at some distant point scattered ashes over this area. Succeeding this epoch, the plains area was depressed beneath the Cretaceous sea, while the Little Belt region remained a land area. This was not, so far as now recognized, a time of mountain folding. The infolds of Cretaceous rocks found at Castle Mountain, just south of the Little Belt Range, and the general upturning of these rocks about the mountain flanks, indicate that this occurred at some later period, which the evidence in neighboring ranges indicates to have been post-Cretaceous.[1]

STRUCTURAL FEATURES OF THE RANGE.

NATURE OF THE UPLIFT.

The Little Belt Mountains form a part of the eastern front of the Rocky Mountain region. They are structurally connected with Castle Mountain on the south and through it with the end of the Big Belt Range. They are formed by a broadly V-shaped uplift, pointing eastward, which disappears beneath the plains at Judith Gap, but is nevertheless continued eastward and reappears in the dome uplift of Big Snowy Mountain. Although connected with the general mountain folding, the Little Belt fold is practically a unit. It differs from the commoner and sharper folds of the region in being a broad, relatively low anticline, having a flat or slightly undulating top and steep sides. The southern border is formed by a secondary fold, pitching eastward and passing into a fault that outlines the margin of the uplift farther west in Volcano Valley and continues westward to Sheep Creek, near Kinney. With this exception no faults of any magnitude were found in the range, except those directly due to laccolithic uplift. The warping is all broad in its features, and there are none of the narrow foldings and overturns seen farther south and west in the mountains near Bozeman and Livingston. On the north and south are troughs of deposition in which great masses of sediments were laid down. The Highwood Mountains on the north show several thousand feet of Cretaceous rock. The Crazy Mountains to the south are composed of 10,000 feet of latest Cretaceous and Eocene (?) rocks, cut by igneous intrusions. The initial dips of these strata away from the Little Belt area probably determined the uplift. There is every reason to suppose that the range uplift is due to lateral compression.

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[1] Weed, Laramie and overlying Livingston formations in Montana: Bull. U. S. Geol. Survey No. 105.

Relation of igneous intrusions to folding.—It is evident, however, that the minor doming and faulting which are observed at all the larger mountain masses of the range are due to igneous intrusions. These mountains are in most cases isolated and individual masses. It will be shown that they accompanied and were a corollary of the large uplift, and locally modified it greatly. To do this it will be necessary first to review the general character, structure, and relation of these igneous masses, a detailed account of which is given in the chapters on the descriptive geology.

DYNAMIC GEOLOGY.

The present structure and altitude of the Little Belt Mountains are plainly seen to be due, first, to a general uplift and folding of the range as a whole, and, secondly, to the presence of large intrusive bodies of igneous rock, of which the largest mountains—in fact, all the individual mountain masses—are formed and to which they owe their origin and present relief. As already stated, these igneous intrusions occur in a variety of ways. The smaller masses form dikes and sheets, the larger ones stocks and laccoliths or allied forms.

Though presenting these different forms and structural relations, it is believed that the intrusions are all the result of the same general cause; that the rocks come from the same general source of supply, and were intruded at the same time or period of igneous activity. This hypothesis finds striking confirmation in the chemical and mineralogical relations of the rocks, as is forcibly shown by Professor Pirsson in the report on the petrography of the igneous rocks which follows this paper.

INTRUSIVE SHEETS.

The areal distribution of the intrusive sheets of the region as shown upon the geologic map does not convey an adequate idea of the abundance and the extent of such intrusions or of the part they play in determining the topographic development of the region. This is due to the fact that the sheets mapped are in most cases shown only at the places actually visited. A better idea of their probable occurrence would perhaps be given if the map had been made more diagrammatic, for many of the sheets are very persistent over many miles of country, though only prominent where the slopes show cliffs or débris heapings of the rocks. For this reason the valleys cut through those areas in which such sheets occur show their outcrops on both sides, conforming to the structure of the rocks in which they are intruded.

The horizons invaded by these intrusions embrace parts of all the Paleozoic formations. As would naturally be expected, the softer and more easily intruded shales are selected, and as the Cambrian rocks present the most favorable conditions for intrusions the greatest number of sheets are found in these rocks. In the Belt formations the rocks yield irregularly to intruding forces, and the ruptures are filled by dikes and irregular intrusions, which are rarely persistent, sheets following along definite bedding planes.

In the Cambrian, on the other hand, the alternation of shale and of beds of sandstone or of limestone offer peculiarly favorable conditions for such intrusions, and they are here most effectively developed. In the higher formations the fissile beds lying between heavy-bedded limestones are the horizons of easy intrusion. The basic sheets are much thinner than the acidic ones, seldom exceeding 15 feet in thickness, and commonly being but 5 to 10 feet through. The acidic sheets, on the contrary, vary from a few feet up to 100 feet in thickness, and are commonly 20 or more feet through. The light-colored sheet rocks consist of rhyolitic and syenitic (or trachytic) porphyrites, and are usually much altered by the normal processes of weathering, but do not crumble down, as do the basic rocks. The basic sheet rocks are mostly minettes, showing considerable difference in grain, being very dense in the thin sheets and crystalline in the thicker; and the latter rocks alter and disintegrate rapidly when exposed, forming rounded exposures or sandy slopes, so that they are seldom conspicuous elements of the scenery. The two types are also contrasted in the effects which they have produced upon the sedimentary rocks in which they are intruded. The siliceous rocks have produced little if any contact metamorphism; the basic rocks, a good deal. This is usually apparent in a baking or hardening of the shales to hornstone and the development of a fine jointing that is independent of the bedding. This metamorphism is, of course, most marked about the largest sheets, and is directly proportional to the thickness of the intrusion.

In the impure limestones secondary minerals are often developed and the rocks marmorized. In those observed instances where the two rocks cut one another the minette is the latest in age. This rock itself shows light-colored dikelets cutting it, but they appear to be aplitic in character and to merely represent parts of the same magma and not independent eruptions

The siliceous rocks are relatively much more abundant, as the sheets are more numerous, and are always much thicker. It is difficult to form an estimate of the relative volume of the two types of rocks. Probably 1:500 would not overestimate the proportion of the lighter-colored rock.

It seems certain that the igneous sheets, some of which can be traced for miles along a certain bedding plane, and which are found upturned and folded with the sedimentary rocks, could not have been intruded after the folding of the strata. No force, however powerful, could inject sheets of so uniform a thickness and so wide an extent into rocks folded as these are to-day. On the other hand, if the sheets were intruded before the folding of the sedimentary rocks they should show some evidence of the movement. It is incredible that the sheets should have been upturned with the inclosing shales, when they were tilted, without showing evidence of the dynamic forces in strain phenomena or cracking of the phenocrysts of the rock. Yet such evidences are lacking in the field exposures and are not revealed by careful examination of the section under the microscope. The only alternative is the hypothesis that the intrusions were injected contemporaneously with the uplift and folding of the strata, their present position being in consequence of such folding and of the "latent" cavities or planes of easy intrusion then developed. This hypothesis seems in perfect accord with the facts observed in the field.

LACCOLITHIC INTRUSIONS.

Position and number.—With the single exception of Yogo Peak, all the prominent mountain masses of the Little Belt Range are formed of masses of igneous rock, whose structural features show that they constitute a group of closely related forms, grading from a typical laccolith to those which may represent plutonic plugs[1] or bysmaliths.[2] The geologic map (Pl. XLI) shows the distribution of these intrusions throughout the range by the exposed areas of igneous rock, or, where this is not yet revealed by erosion, by the outlying domes of older rocks, which are believed to cover such intrusions.

Fig. 47 is a ground plan of these intrusions. This diagram shows the relation of the laccoliths to one another and their distribution in the range. The circular areas marked by letters represent the different mountain masses, the curved line representing areas of uplifting or doming of the strata where this has occurred, or of the boundary of the igneous rock where the intrusion has not disturbed the adjacent strata. The uplift of the whole range is defined by a line which marks very nearly the outer boundary of the Carboniferous limestones.

General features.—It is evident from fig. 47, which is based upon the geologic map, that the intrusions occur along the northerly border of the uplift, most of them being situated on its northern limit or monocline. By reference to the geologic map it will be seen that they occur only where the Belt terrane is wanting. It will also be seen that the igneous rocks are in contact with strata of various ages, and that only in the uplifts outside of the range, as at Skull Butte, is the symmetrical doming of a typical laccolith shown by concentric outcrops of the different formations. The map shows plainly that the intrusions associated with the main range uplift the strata about a part of their periphery in some cases, and break through the beds in another part, while in other cases they show only a narrow zone of abrupt uplifting or none at all. These relations are also seen in the vertical sections across the range shown in folios Nos. 55 and 56 of the Geologic Atlas of the United States.

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[1] I. C. Russell, Jour. Geol., Vol. IV, 1896, pp. 23-43.

[2] J. P. Iddings, Jour. Geol., Vol. VI, 1898, p. 705.

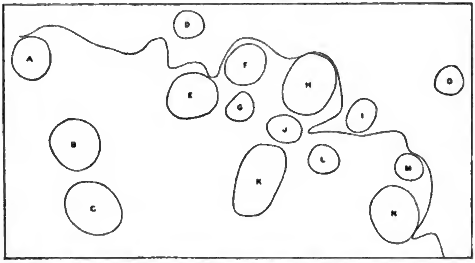

Fig. 47.—Diagram showing distribution of laccolithic masses and related intrusions in Little Belt Mountains. The outer line shows the limit of pronounced displacement or uplift (the springing line of the range), the rudely circular areas that of the laccoliths and related intrusions. A, Tiger Butte laccolith; B, Thunder Mountain dome; C, Tillinghast Mountain dome; D, Kibbey Dome; E, Barker Mountain; F, Clendenin and Otter Mountain dome; G, Mixes Baldy dome; H, Taylor Peak and Wolf Butte; I, Foothill Dome; J, Steamboat Mountain; K, Big Baldy dome and Steamboat Mountain; L, Dry Wolf dome; M, Sage Creek Mountain; N, Ricard Mountain; O, Skull Butte.

It is apparent that the asymmetric laccolith is the prevailing type. These sections and the geologic map also show that the asymmetric or faulted side of the laccolith is on the outer side—that is, next to the plains country, and away from the mountains, and that it coincides with the steep dip marking the flank of the fold. In other words, the asymmetric sides of the laccoliths coincide with the monoclinal fold along the flanks of the range anticline.

Size.—The size of these intrusive bodies varies. Big Baldy, the largest, shows a surface exposure of 3 by 5 miles, and a vertical extent which is believed to be very nearly its original thickness of 3,000 feet at the center. The Barker Mountain mass has a diameter of about 4 miles, as shown by the doming of the strata, and the mass is probably about 3,000 feet thick in the center. The Steamboat, Sage, and Ricard mountain masses are smaller, the folding indicating a base about 2 miles in diameter.

Contact metamorphism.—These intrusions have produced but little contact metamorphism of the sedimentary rocks. At the immediate contact there is a hardening and alteration of the adjacent rocks to hornstones or marbles, but this extends at most only a few yards from the igneous rock. So far as observed, this alteration affects a greater thickness of rock over the top of the intrusion, as at Steamboat Mountain, than it does along the sides.

Character of the rocks.—The rocks constituting these intrusive masses are uniform in mineral composition throughout the whole extent of each body, but exhibit a limited variability of texture, ranging from dense aphanitic forms at the contact to finely crystalline textured porphyries in general. Those of the same type differ somewhat in the different intrusions, showing variations in texture and in the relative proportions of the component minerals, but the rock nevertheless preserves its general character and habit. The rocks are classed, first, as Barker porphyry, the prevailing type, which grades into diorite-porphyry at Steamboat Mountain; and, second, as Wolf porphyry. Both types are granite-porphyries, and are fully described in the report following this. Their field relations are given in the descriptive geology of the range.

Jointing.—The rocks of each type show characteristic jointing, but the jointing is more dependent upon texture than upon mineral composition. The Wolf porphyry at Wolf Butte shows typical granitic weathering, with well-marked jointing, forming great castellated crags and rounded bowlder masses, the so-called "Woolsack" structure. In general, however, the rock is crumbly and seldom forms good exposures. The Barker porphyry breaks with a conchoidal platy fracture, rarely showing massive forms. The best examples are those seen in the Big Baldy amphitheaters, illustrated in Pls. XLVIII, *B*, and XLIX, *A*. The contact forms of both types show a fissile or platy structure, with the planes parallel to the contact. These platy masses break up into rather small, angular blocks, due to minute joints—the common weathering of dense rhyolitic porphyries.

Horizon intruded.—In no case has the bottom contact of these intrusions been seen. The correlative evidence afforded by the stratified rocks about the intrusion is, however, quite conclusive that the intrusions rest on a floor of Archean gneiss or upon the basal sandstones of the sedimentary series. The horizon invaded is therefore the shale formations of the Cambrian, and the later formations of this age are seen uplifted about and encircling many of the intruded masses.

Depth of intrusion.—The Archean rocks are covered in the vicinity of these intrusions by a thickness of 2,200 feet of strata. The Quadrant formation, 400 to 600 feet, and possibly the Ellis, 200 feet, were also probably present, but have been removed in the denudation of the range. How much of the Cretaceous, if any, formerly covered the range is not known. The shore-line features observed about the flanks of the range and their absence from the infolds of the region seem to indicate that these rocks never covered the Little Belt area. Skull Butte, which is believed to be a concealed laccolith, is still covered by Jurassic rocks and shows the Cascade formation (Lower Cretaceous) sharply upturned by it, so that it undoubtedly once covered the dome. This would mean a total cover of about 4,000 feet.

None of these intrusions of this character occur where the Algonkian rocks are found; that is, they are absent where the sedimentary section is greater than 4,000 feet and were not formed under a cover of great thickness.

Extent of denudation.—The intrusions are seen to-day in various stages of denudation and erosion. At Thunder Mountain the original surface has been carved into a broad peak; at Big Baldy Mountain the smooth, rounded contour is preserved on one side, but the other is deeply cut by amphitheaters. Barker Mountain is a bared but as yet almost uneroded laccolith, showing the original smooth, curved upper surface of the intrusion. Steamboat Mountain shows the cover of sediments just cut through, exposing a small area of the igneous core. The Kibbey dome is believed to conceal a laccolith; the softer beds have been removed from the core, but the dome of Carboniferous rocks are only slightly attacked by erosion. At Skull Butte the Mesozoic rocks are not yet pared off, though the center of the dome is deeply trenched by a small drainage originating in this butte. Thus every stage is seen, from intrusions still covered by the domed strata to those almost completely denuded and deeply scored and carved into peaks.

The Kibbey and Dry Wolf Creek domes are crossed by streams flowing in deeply trenched channels cut in the arch. This peculiarity is due, as Gilbert has shown for similar examples in the Henry Mountains,[1] to the formation of planation terraces—the work of streams radial from the mountains cutting across the soft Mesozoic rocks. As degradation progressed the Carboniferous limestones of the domes were uncovered, and, lateral corrosion by the stream being checked by the harder rock, the channel became fixed and a canyon was carved, while the dome of limestone was, at the same period, left in relief by the general degradation of the region.

Accompanying dikes or sheets.—There is a general absence of dikes connected with these intrusions. Only one case was found of a dike that owes its origin to a laccolith or related form of intrusion. This is on the summit of Ricard Mountain. This is in accord with the facts observed in the Judith Mountains, but quite different from the Henry Mountain laccoliths. Intrusive sheets are, however, often found in the upturned beds about the intrusions. They are usually of little thickness, the larger sheets seen in the range owing their origin to the Yogo Peak center.

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[1] Geology of the Henry Mountains, p. 126.

Form of intrusion.—The intruded masses whose occurrence and characteristics have been summarized in the last few pages have been referred to as laccoliths. Their cross sections are shown in figs. 43, 44, 45, and 46. In none of the denuded laccoliths is the simple, symmetrical, dome-shaped uplift realized. All the masses show at least a short arc on one side, along which the strata are broken, and the igneous rock has risen to a higher horizon across the fractured edges of the beds. This is the typical asymmetric laccolith.

Barker Mountain, a cross section of which is given in fig. 43, shows this structure. On three sides the rocks are flexed and arch over the intrusion; on the remaining side they are broken and faulted. A section made in a different direction would show this better than that in the figure, which is intended to show, not the normal doming of the beds, but the asymmetric character of the intrusion.

The cross section of Thunder Mountain (fig. 46) represents a different form of intrusion. It is easy to see that there may be every gradation, from the asymmetric laccolith, whose lack of symmetry is confined to a single side or a short arc of its circumference, as seen in ground plan, to one in which half the circumference is a line of fracture and fold, and from this to one that is fractured for three-fourths of the periphery. If we assume the contact plane is all fracture and no fold it becomes a bysmalith—that is, a laccolith in which the arched part equals zero. The laccoliths of the Little Belt Mountains are all asymmetric ones, and show various gradations into the bysmalith. It is noticed that the laccoliths are smaller in area than the bysmaliths when the rock is the same in both. There are three bysmaliths, viz: Thunder Mountain, Mixes Baldy, and Big Baldy Mountain. The Wolf Butte and Steamboat Mountain intrusions are intermediate in type; the remaining six are asymmetric laccoliths of the Barker Mountain type, while the three outlying domes may belong to any one of these groups, since in each the intrusion is covered by an arch of sediments.

The common form found in the Little Belt Mountains is, however, clearly entitled to the name laccolith, being symmetric for the greater part of the circumference. Moreover, as stated by Gilbert, "if the strata had experienced anterior displacements, so as to be inclined, folded, and faulted, a symmetrical growth of laccoliths would have been impossible."[1] Cross,[2] in discussing the laccolith, says:

> In regions where the beds are under orographic stress almost or quite to the point of folding, a magma would find intrusion on certain planes a comparatively easy matter. Such conditions are illustrated by the sheets in the spring of the arch of strata over the laccolith, fig. [48], and it seems probable that such occurrences as those of the Musquito Range and Ten Mile district, where many of the sheets are intruded very regularly, represent localities where lateral pressure has already overcome the gravity of the strata to a great extent, and the intrusion planes were planes of easy parting.

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[1] Geology of Henry Mountains, p. 98.

[2] Laccolithic mountain groups: Fourteenth Ann. Rept. U. S. Geol. Survey, Part II, 1893, p. 236.

He explains the asymmetric form of the Mount Marcellina laccolith by supposing "a line of weakness * * * from axial tension, preexisting fracture or resistance offered by an earlier intrusion—the intruding magma would develop this into dislocation."

These statements apply with peculiar force to the conditions found in the Little Belt Mountains. The common type is like that of Mount Marcellina, given by Cross. Fig. 48, copied from Cross, shows an ideal restoration of laccoliths and strata above it, based upon a profile section. If this be compared with the section of Mount Hillers, in the Henry Mountains, as given by Gilbert (fig. 49), it will be seen that the conditions observed there and those supposed by Cross are similar, but the interpretation is very different. The Thunder Mountain laccolith shows a cross section (fig. 46) strikingly like that of Hillers. It is believed that the facts observed in the Montana region are in accord with the interpretation given by Cross. If the right-hand half of the

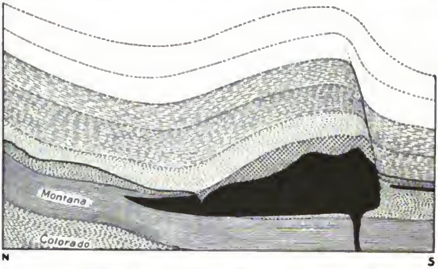

FIG. 48.—Profile section through Mount Marcellina, with ideal restoration of laccolith and cover (Cross).

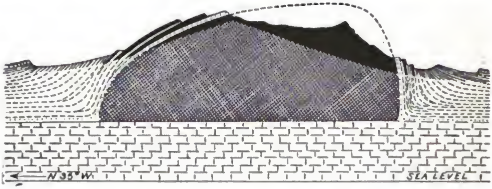

FIG. 49.—Ideal cross section of Mount Hillers laccolith, Henry Mountains (Gilbert).

diagram (fig. 48) be revolved about a vertical axis, the resulting form would be the bysmalith of Iddings, as shown in his diagram of Mount Holmes, of the Gallatin Range of the Yellowstone National Park (fig. 50). It is easy to conceive of all gradations between laccoliths asymmetric for short arcs of the ground plan, through those that are asymmetric for half the circumference, to the typical bysmalith. It is believed that the Little Belt masses present actual examples of all these forms.

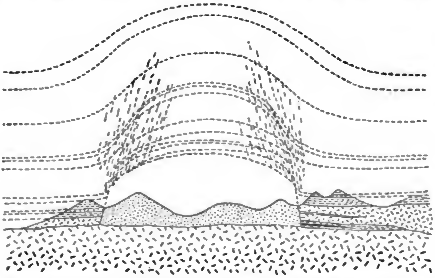

FIG. 50.—Ideal cross section of Mount Holmes bysmalith, Yellowstone National Park (Iddings).

The occurrence of dikes filling fissures formed by extensile strains, due to the stretching of the strata over the laccoliths, is a very uncommon feature in the Little Belt Range, owing, it is believed, largely to the shaly nature of the overlying strata. The pipe of rhyolite-porphyry cutting the limestone that crowns Ricard Peak is believed

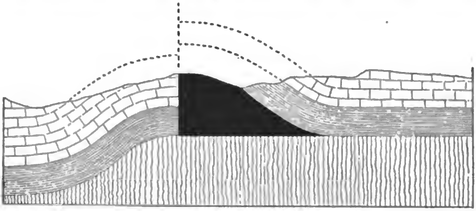

FIG. 51.—Ideal cross section of northern flank of Little Belt Range, to show relation of asymmetric laccolith to fold or faulting of uplift.

to be the filling of a fissure due to such extensile strain. Gilbert's hypothesis of stretching is, however, based upon hydrostatic pressure acting on horizontal beds. If the beds were flexed or being flexed by orographic forces, there would not be a stretching of the strata next to the laccoliths, but rather a compression, while the uppermost layers of the arch would be stretched, though the well-bedded stratified rocks, being coherent, would tend to fold rather than rupture, like the beds of the Colorado locality described by Cross.

Theory of origin and peculiarities of form of laccoliths.—The origin of laccoliths, originally treated by Gilbert, has since been discussed by Cross, and recently by Pirsson. The former writer shows that relative "densities of intruding lavas and invaded strata" are not the cause, and finds in forces of different intensity, if not in kind, the factors determining whether the intrusion shall be a laccolith or stock.[1] Pirsson,[2] in a very lucid and practical treatment of the subject, calls attention to the physics of the problem and the analogy between sheets and laccoliths. Particular emphasis is laid upon the viscosity of the intruding magma, and in this and the rate of injection he finds the main factors determining the character of the intrusion as a sheet or laccolith, with upward force of magma, gravity, load of sediments, and their resistance to splitting as other factors. Owing to viscosity, the force is not transmitted as in a perfect fluid, and in a supposed instance, where the magma is intruded between strata when the sheet-like mass becomes of a certain radius, the force is greater over the supply pipe than elsewhere, and the strata arch up. The convexity of a laccolith is a function of the viscosity of the lava.

In the same way, it is believed that if the force be great, fractures will occur and a bysmalith be formed instead of a laccolith. It is only carrying the process a step further, and the bysmalith bears the same relation to the laccolith that the latter does to an intrusive sheet. Pirsson [3] finds in rapidity of supply of the magma the cause why stocks and not laccoliths are formed, the magma "spreading out laterally as the lateral resistance diminishes, rupturing and tearing up the beds * * * or under lighter loads expanding laterally and uplifting beds so as to simulate laccoliths when seen from above, but having no proper floor." In the writer's opinion, such fan-like expansions are most apt to form in clay shales and similar easily ruptured beds.

Summarizing the conditions determining the nature of the Little Belt Mountain intrusions, we find that—

1. Sheets occur in easily separable, well-bedded strata; the intrusive rocks are of various composition.

2. Laccoliths occur along planes of easy intrusion (usually between a solid resistant floor and overlying massive beds competent to form

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[1] Loc. cit., p. 240.

[2] L. V. Pirsson, in Geology of Judith Mountains, by Weed and Pirsson: Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, 1898, p. 586.

[3] Loc. cit., p. 587.

arches) when the invading magma is relatively siliceous, and hence viscous.[1] Theoretically they should have a larger horizontal area than the sheets, other conditions being equal. Asymmetry of form results from local weakness of the cover, due to one or more of several causes.

3. Still more irregular laccoliths, or those forms called bysmaliths, will form instead of true laccoliths when the diameter or the ascensive force is greater, and hence causes more rapid uplifting.

These three forms of intrusion all grade into one another, and are similar in that they all are covered by an arch of strata domed by the intrusion. Gradations from the laccolith to the stock will occur when there is a well-developed line of weakness or fracture along one side of the laccolith. It is merely a question of the ratio of resistance of lateral expansion and uplift to fissuring and ascension.

In regions where easily separable strata of very unlike character, such as massive limestone alternating with micaceous shale, are folded by orogenic forces, it is evident that if molten magma has access to the folds intrusions will be easy in the span of the arch or along the slip planes on the limbs of the fold. The theoretical shape of intruded masses in the span will give a crescent-shaped cross section, like the "saddle reefs" of the Australian ore deposits, which are strictly analogous deposits of quartz. This form of intrusion is, as Iddings has pointed out, the one to which Suess applied the term batholith—a term now generally used in a broader sense. Such meniscus-shaped intrusions have been found by the writer on the summit of anticlines in the Castle Mountain region south of the Little Belt Mountains.

Unlike the laccoliths of the various localities hitherto described, the Little Belt Mountain examples are in a region where orographic folding has occurred. The sedimentary rocks consist of well-bedded strata resting on Archean gneisses. The lower member of the series consists of 900 feet of shale alternating with thinly bedded limestone, the middle member of 1,000 or more feet of massive limestone, the upper member of 1,000 or more feet of shale and sandstone. It is the same series which under tectonic forces always formed folds in this region.

Summary.—In the Little Belt Range the observed facts show that the intrusions did not occur before the uplift nor after the uplift of the range. The hypothesis is advanced that the igneous intrusions accompanied the uplift, and that they invaded those places where the orographic stresses furnished planes of easy entrance, so that the force causing the range uplift and the upward pressure of the ascending magma worked together. The laccoliths occur mainly on the flanks of the mountain uplift because it furnished faults or lines of weakness for intrusion, especially along the outer sides. The presence of the laccoliths on the northern part of the range only is in accord with the hypothesis of a relatively light load. Where the many thousand feet of strata of the Belt terrane lie between the gneisses and the Cambrian beds no laccoliths occur. Where the Belt beds are absent the intrusions had less than one-fourth of the load to lift.

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[1] Laccoliths of basic rock occur in the Highwood Mountains of Montana and elsewhere, but are not considered here, the contrasted types being those of the Little Belt region only.

The asymmetric character of the intrusions, and the fact that the asymmetric side is always toward the open plains, are quite in accord with the theory just given, as the line of monoclinal flexure on the flank of the range anticline would also be a line of weakness, which the ascensive force of the magma, added to the compression and folding stresses of orographic movement, would tend to develop into a dislocation. This might readily pass into a fold upward and be revealed only by erosion.

GRADATION BETWEEN LACCOLITHS AND STOCKS.

Intrusive stocks may show fanlike sections and dome up the strata. In giving the conditions which he believes favor the formation of a stock rather than a laccolith, Pirsson mentions the conditions which the present writer believes determine the formation of bysmaliths—viz, too rapid forcing of magma upward for adjustment of load and arching of strata. It is, however, a question how far the facts carry out Pirsson's hypothesis that "as the magma ascends from one horizon to another it continually spreads out laterally as the lateral resistance diminishes, rupturing and tearing up the beds and carrying their material with it;" or "diminishing lateral resistance, the lighter load may permit the magmas to seek relief by lateral expansion, and in so doing they may lift the lighter beds above them and solidify beneath them; then from above they would simulate a laccolith, but differ in having no proper floor."

The soft Mesozoic beds which prevail in the Judith Mountain examples are readily ruptured and do not flex well, but these formations are not present in the Little Belt examples, and the observed facts do not accord with this hypothesis.

INTRUSIVE STOCKS.

There are three intrusive masses in the range which differ in occurrence from those already described, and are best classed as stocks or intrusions breaking abruptly through all other rocks with a more or less vertical contact. The most northern of these masses occurs in the Barker district, and is a mass of rather evenly coarse-grained syenite about 1½ miles across. But little is known of its structural relation further than the fact that it is later than the intrusive sheets of the vicinity. No connection with the laccoliths is known.

YOGO STOCK.

In the central part of the mountains there is a chain of peaks extending in a general northeasterly direction 13 miles from Yogo Peak, the second highest summit of the region, to Woodhurst Mountain. This chain, to which the name of range might perhaps be applied, is geologically of very different origin from the mountain types of the rest of the district, and finds its nearest known counterpart in the Ruby Range of Colorado, described by Cross.[1]

At the southwest end of this chain is a stock whose culminating point is Yogo Peak. This is connected by numerous dikes with another stock to the northeast, which is for convenience designated the Woodhurst stock, as its extreme end forms Woodhurst Mountain. These two stocks and the connecting dikes constitute the filling of a great break or fissure extending across the eastern side of the Little Belt Range. The Yogo Peak stock appears to have been a conduit or center for the igneous activity of the region; the Woodhurst stock is in places a broad dike-like intrusion, breaking up through the rocks without regard to their structure, but at Woodhurst Mountain is laccolithic in character. It constitutes, in fact, a transition form between a stock and the laccolith-bysmalith types. Moreover, the rocks of this stock show an essential identity in composition, and even in details of structure, with those of the laccoliths. This forms the bulbous eastern extension of the remarkable fissure line noted above. It consists of a mass of coarsely granular rocks, whose structural relations show that it was a center of igneous activity.

The sheets which encircle the center, and the dikes, which show a well-marked radial arrangement about it, indicate that this stock formed a center from which intrusions were sent out in various directions and in various forms for many miles into the rocks surrounding it. There is, however, no positive evidence to show that it had any direct connection with the varions laccoliths of the range. The rocks composing the stock are also of unusual interest, since they show a systematic gradation of types from basic to syenitic rocks, and this arrangement has a definite structural significance.

General geology of Yogo stock.—The rocks of the Yogo stock, together with those of the encircling sheets and radial dikes, form a natural group showing great variability of composition and structure. The stock rocks grade into one another, but are sharply contrasted in some small closely adjoining portions. The granular nonporphyritic types, the syenite, monzonite, and shonkinite, occur only in the stock and its larger offshoots, while the finer-grained porphyritic rocks occur in the stock and in dikes and thinner sheets intruded in the sedimentary rocks for many miles about it. The syenitic types vary in structure and composition in the different occurrences, but the changes in a single area are not rapid or marked except at Yogo Peak. At this locality the different types occur in such a manner as to suggest differentiation in place. It is possible that successive injections occurred, but the general uniform gradation of the types is against this view. There is no reason to believe that the material ever found an outlet at the surface, but the stock appears to be the site from which not only the great mass of the stock itself but also the lesser masses of the encircling dikes and sheets were sent out. The variability of grain, the banding of some of the smaller portions of the Yogo rock, the little included masses of porphyry, which seem to fade into the coarser-grained rock, and the other variations observed in the field could have resulted from a differentiation of the mass. This might possibly have differentiated before the final act of intrusion and have been slightly mixed during the final movement, as explained in the petrographic report following this paper. If this is true, the differentiation observed is a result of cooling after injection. Since cooling must have been about the same throughout this large body, it must have been one cause of the variation in character, since rock structure depends upon both temperature and chemical composition. The magma of the main stock would remain molten much longer than in the smaller fissures, and it is therefore in general much coarser grained. There is no evidence at Yogo Peak of very fine-grained or dense rock at the contact, and at the time of the final consolidation the surrounding rocks, as the metamorphism shows, were undoubtedly thoroughly heated, so that very fine-grained varieties were not formed.

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[1] Laccolithic mountain groups: Fourteenth Ann. Rept. U. S. Geol. Survey, Part II, 1893, pp. 199-201.

The porphyries forming part of the stock and the intrusive sheets and dikes may be divided into light-colored feldspathic and basaltic types. The light-colored rocks contain a little hornblende and biotite, and only the basaltic or trap-like forms contain augite. The light-colored acidic rocks are cut in places by the dark-colored basic ones, and vice versa, and it is therefore certain that there were successive periods of fracturing and of dike filling. The evidence also shows that the intrusion of the great stock itself was practically simultaneous, though there may have been several acts of dynamic action closely following one another, all forming one great period. When the first dynamic action fissured the sedimentary strata the magma at hand would fill the larger fissures and penetrate all the smaller cracks and solidify as sheets and dikes. There is no evidence that the stock broke out along a general syncline, which seems to be the most favorable condition for the injection of such large masses. That the force was an uplifting one is, however, shown by the abundance of intruded sheets.

The intrusion of the sheets is generally parallel to the bedding of the strata, except in places where for short distances they may break across the beds. The association of light-colored acidic and of dark basic types is oftentimes very close, and sometimes they occur as parts of a continuous rock mass, but in no case observed is there distinct evidence of differentiation in the sheets, such as that described by Merrill[1] in the Gallatin Valley, and as seen by the authors of this memoir in the neighboring Highwood Mountains. The thicker acidic sheets—from 75 to 100 feet thick—are light-colored rocks, resembling types occurring in the Yogo stock. These sheets show plainly that in large part they were intruded at a time of uplift, when the stresses produced by dynamic forces aided in the injection of the igneous rock. The intruded sheets vary greatly, both in thickness and in horizontal extent, and present corresponding variations in texture and in mineral composition. In the thinner sheets, which are from 1 to 25 feet thick, the acidic light-colored rocks exhibit a very uniform habit. They vary in texture from dense aphanitic to fine crystalline forms, and, except in the very thinnest sheets, they exhibit an abundance of white feldspar phenocrysts or embedded crystals, which spot the rock and give it a typical porphyritic appearance, and smaller quantities of black ferromagnesian silicates, hornblende and biotite, the relative proportions of which vary in different forms. Considerable variations in color are shown, and are due to variations in the amount or character of the groundmass and of the phenocrysts. As a whole, the rocks of the stock and its connected intrusions form a very complex group, intimately connected in geologic occurrence, and they are the result of a single period of igneous activity, forming a series exhibiting both transitions and contrasts in composition and in structure.

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[1] Proc. U. S. Nat. Mus., Vol. XVII, p. 637.

The character of the intrusion is such that it shows that the force was great enough to force the magma upward and disrupt the strata without greatly uptilting the beds, as previously mentioned. The mass thus injected is some 14 or 15 miles long, by about a mile wide, forming a continuous rock body, of which Yogo Peak is the southwestern end. Although accompanied, as stated, by numbers of sheets and some dikes, there has been no such vast amount of radial fissuring of the surrounding strata as occurs in the Crazy and Highwood mountains of this same general region, where the intrusious of streaks are in the soft Cretaceous strata, with great surrounding zones or dikes. This is probably due to the harder, more resistant character of the Paleozoic beds. The greatest amount of fissuring of the strata appears to be at the northeast end, where the intrusion is connected by dike-like masses through the sediments with the large intrusive masses of Schoppe and Sheep mountains, which carry the whole line of intrusions to the northeast along a great general plane of fracturing.

These intrusions appear to lack the depth and massiveness of the great Yogo stock, since they terminate toward the northeast with a distinct laccolithic phase of intrusion, and the rock has also the porphyritic structure of the laccoliths. And as in the laccoliths, there is no perceptible amount of differentiation in place.

How far above the present surface the Yogo stock once extended is of course uncertain, but it is clear that a great load of sediments above it, and probably a considerable portion of igneous rock itself, have been removed.

RELATION OF STOCKS AND LACCOLITHS.

The basic dikes and all the dikes found radial from the Yogo center are basic in character, are the latest rocks, and cut igneous rocks as well as the sedimentary ones. The minette dikes are believed to be of the same phase as the minette sheets, and in some instances at least to be directly connected with and to form a part of such sheets.

On the other hand, the dikes of analcite-basalt and associated types cut through are later than the laccoliths, acidic sheets, minettes, or the granular rocks of the core. They can not, therefore, be offshoots from the massive rock of Yogo Peak, but must come from some deeper-seated source or the still liquid lower part of this Yogo stock. Both the basic dikes and sheets are found at far greater distances from the Yogo stock than the acidic rocks.

The fact that the dikes are the very latest intrusions of the Yogo series is in accord with similar observations made by the author elsewhere in Montana. It indicates that the final forces produced a fissuring of the rocks adjacent to the stock. The analogy with the hot springs of Yellowstone National Park is worthy of notice in this connection. While the hot waters have a free outlet they build up a mound about the spring, line the conduit with a calcareous deposit, and, penetrating every fissure adjacent to the conduit, tend to fill it up with a fresh deposit. There is thus gradually formed a definite conduit with solid walls. When deposition arches over and contracts the outlet, as is often the case, the water level is raised to keep pace with the building up of the deposit, until finally a level is reached where overflow all but ceases, and the rapidly forming travertine covers over and sometimes completely closes up the spring. The gases of the spring waters thus confined, together with an increased head resulting from the accumulation of water due to lack of outlet, make a gradually accumulating force, which, if it can not break a new outlet from some point in the conduit walls, will split the formation about the spring in radiating cracks, which generally extend far enough outward to give a much lower outlet for the water and thus renew the life of the spring.

THEORY OF DIKE FORMATION ABOUT IGNEOUS CENTERS.

If we suppose that an igneous magma, under pressure, penetrates between sedimentary beds to form intrusive sheets, or raises them to make laccoliths, then chills in the pipe or central stock, but remains still liquid below, the result of such intrusions is to strengthen the surrounding structure and to make further intrusions as sheets more difficult until the accumulated pressure brings about a final rupturing of the area adjacent to the center of activity, with accompanying intrusion of the differentiated magma, the regulus of the fluid, into these fissures, forming dikes. This, in fact, appears to have taken place at Yogo.

CHAPTER VIII.

NOTES ON THE ORE DEPOSITS OF THE LITTLE BELT MOUNTAINS.

HISTORY AND DEVELOPMENT OF MINING IN THE REGION.

The first recorded discovery of valuable deposits of the precious metals in the Little Belt region was made on October 21, 1879, at Barker. Several extensive bodies of rich silver-bearing lead carbonate were found in that district, and it became a producer in 1881. The same year that the Barker deposits were discovered the discovery of gold in the alluvial gravels of Yogo Gulch resulted in an inrush of fortune seekers to that locality. The attention thus directed upon the Little Belt Range resulted in the general exploration of the mountains in this and succeeding years. The carbonate and silver-lead deposits of the Wolf Creek district, north of Yogo, were developed, and many hundreds of lode claims were staked out in various sections of the range. The Neihart deposits, discovered in 1881, attracted relatively little attention at first, but have proved the most valuable and permanent source of wealth of the entire region. The total production of the different camps can not be given, nor is it possible to give that of any of the separate districts with any degree of accuracy. The entire product of the Barker and Neihart districts for 1882 was only $65,000 to $70,000. That of Neihart up to 1898 is estimated at $2,140,000. In the year 1883 mining development reached high-water mark in all but the Neihart district, where it had just begun. The exhaustion of the bodies of rich carbonate ores resulted in stagnation and in a period of waiting until railroad communication was established. But little development work was done, though it was very generally believed that a rapid revival would follow the advent of the railroad. In 1891 a branch line of the Montana Central Railroad (now part of the Great Northern line) was built from Great Falls to Neihart and Barker, and another "boom" period began. The well-defined veins and rich ore bodies of the Neihart region naturally directed especial attention to that district, and extensive development of mines and the usual mushroom growth of a mining town followed. Since that time the history of the mining development of the region is practically that of Neihart, the Yogo and Running Wolf districts having been but small producers. Since the ore bodies first discovered proved limited in extent, sufficient development work has not been done to prove either the value or the worthlessness of the properties, and they have been idle the larger part of the time. Local excitement over discoveries on King Creek, Tenderfoot and Pilgrim creeks, Tiger Butte, Sage Creek, and other localities proved short lived, and though small amounts of ore have been packed out from various claims in these districts no producing mines have been developed. Up to the present time the geologic work reveals no such well-defined veins as those of Neihart, the deposits being mainly along contacts or associated with igneous intrusions.

The prevailing inactivity, outside of the Neihart district, has made it difficult to obtain valuable data about the ore deposits. Wherever the workings were accessible they have been visited, but in many instances the surface geology and such facts as could be gathered from an examination of the ores and dump heaps, together with the information given by persons familiar with the region, are all the data available for this memoir. Moreover, it should be remembered that the gathering of information upon the ore deposits was merely incidental to the survey of the areal geology of the mountains on a 4-mile-to-the-inch scale. Though the work was not in any sense a detailed study of the ore deposits of the region, it is confidently believed that the facts presented will be of general interest. As an account of the general geology of the region has already been given, the following pages are devoted entirely to a description of the ore deposits. The Neihart district, the principal producer of the region, is first described. This is followed by notes on the Barker district, the Yogo district, the Yogo sapphire mines, and the iron-ore deposits of the region.

ACKNOWLEDGMENTS.

The writer acknowledges with much pleasure the courtesy and assistance extended him by the mining men of Neihart and the other districts visited. To Mr. William Monroe thanks are especially due for copies of his claim map of the district and of individual mine surveys, as well as for the use of his office and many acts of kindness. Acknowledgments are due to Mr. D. C. E. Barker, not only for many courtesies, but for the gift of particularly fine specimens of the rich ores of the Big Seven mine. Messrs. Jonathan McAssey, Daniel Lenny, and James Henley also were untiring in their kindness. The history of Neihart has been largely derived from the account by Mr. E. N. Abbot in the Neihart Herald. Thanks are also due to Messrs S. S. Hobson and Matthew Dunn, of the Yogo sapphire mines, for courteous attention and for specimens from the workings.

NEIHART DISTRICT.[1]

DISCOVERY AND DEVELOPMENT.

The ore deposits of Neihart were discovered in July, 1881, by a party of prospectors from the neighboring town of Barker, and the first claim that was located, the Queen of the Hills, is still worked. The news of the discovery soon reached Barker, when several parties started for the locality, and a large number of claims were staked out in the first few weeks. The camp was named after J. L. Neihart, but the district was called the Montana district, and has never been officially organized.

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[1] Montana district, unorganized, of United States Land Office.

In 1882 a small settlement had sprung up, a wagon road was cut through to White Sulphur Springs, and small amounts of rich ore were packed on horseback to the Barker smelter. The first mine to be developed by outside capital was the Galt, bonded by Governor Hauser in 1883. In that year the district was visited by Prof. W. M. Davis, of the Northern Transcontinental Survey, and in April, 1884, Prof. J. S. Newberry visited the camp on behalf of capitalists, who bonded the Mountain Chief. The year 1884 was a lively one for the new camp. The Queen, Galt, Ball, and Mountain Chief mines were being actively developed and began shipping ore to the Omaha smelter. These ship-

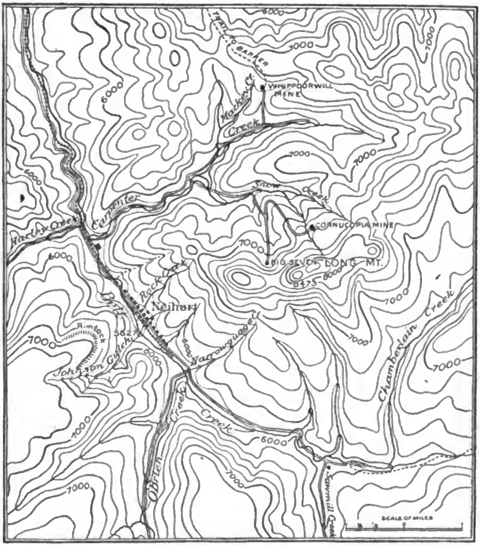

FIG. 52.—Map of Neihart district.

ments netted the owners $200 a ton, after deducting $100 per ton for freight and treatment. The Mountain Chief was purchased for $18,000 by the Hudson Mining Company, which spent over $10,000 in developing the property, and acquired a group of six claims. The character of the ore uncovered by these workings led to the building of a concentrator and smelter by this company in 1885–86. About 1,000 tons of concentrates and $50,000 to $60,000 worth of bullion were made. The works closed down in 1887, owing to the exhaustion of the rich surface ores and to the encountering of ores at slight depths carrying but 15 to 40 ounces of silver. It was found difficult to concentrate this ore, the tailings being, I am told, as high as 9 to 15 ounces of silver; and as large sums had meanwhile been expended in unproductive development, the enterprise was abandoned.

In April, 1885, a group of claims acquired by the late Colonel Broadwater were consolidated to form the Broadwater mine. This property was vigorously exploited for a few months, but the ore bodies opened proved disappointing to the promoters, and work was soon suspended. These two failures gave the new camp a decided setback. Transportation was costly, low-grade ores could not be successfully mined; so from 1887 to 1890 the camp was deserted by all but its most sanguine men. In 1890 the building of a railroad line to Great Falls was assured, and a new era at once began. People flocked in from all over the State, buildings sprang up like magic, a large number of mines were bonded and sold, and mining development was actively carried on. The railroad was completed on November 15, 1891, giving cheap transportation to the new smelter at Great Falls and to similar establishments elsewhere. The result was that development work had progressed so far in 1893 that a number of properties were in a condition where a steady output was assured, when the price of silver took its final drop in that year. It came like a thunderclap to the little camp. Work was suspended on all but a few mines until something of the future was known. From this blow the camp has not fully recovered, though the rich ores of the Florence, Benton, and Big Seven mines were profitably worked despite the low price of silver, more especially as those of the two last-named properties carried high values in gold. Before the drop in silver, in this same year, exploratory work upon the Broadwater mine by its new owners had developed large bodies of rich galena ores, and this mine has continued to produce and ship ore up to the present time. From the figures given for various mines the total production of the district up to 1898 is estimated to aggregate 4,008,000 ounces of silver, $800,000 in gold, and 10,000,000 pounds of lead. As the ores have been very largely shipped outside the State, and the properties have changed hands several times, absolutely reliable returns could not be secured.

While a large part of the known area of the district has been patented, there is reason to believe that development of the camp has just begun. Very few of the veins known to exist have been explored.

Where tunnels have been driven few, if any, upraises or crosscuts have been made. Discoveries in 1897 of rich ores on virgin ground on Mackey Creek, of the extension of the veins into the quartzite hitherto believed to be barren, and of the existence of rich ores south of Belt Creek show that these places have been overlooked in the past. The steep slopes are admirably adapted for the development of many of the veins by adit levels, and this system is generally followed. Cooperative working of several veins by a common level will undoubtedly cheapen development. Water power is abundant and close at hand, while the coal mines of Belt, only 40 miles away, insure a supply of cheap fuel. Timber is abundant and near at hand, though large mine timbers are relatively scarce.

The leasing system of workings has been adopted in a small way and is likely to become a powerful factor in the development of the camp. At present the rates are based upon an assurance of $3 for a day's work, a royalty of 10 to 15 per cent being exacted. The equitable system in vogue in Colorado of a definite and signed contract, with sliding scale of royalty according to the value of the ore produced, seems a sure way to develop many properties now idle into paying mines. Concentration of the low-grade ores now thrown aside must of necessity come soon. Several attempts have been made of late years to build works for this purpose, but so far without success, yet even at the present price of silver the future of the district is thought to be brighter than is generally believed.

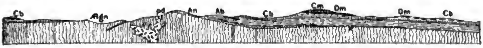

FIG. 53.—Northwest-southeast section across Neihart district. Cb, Cambrian, Barker formation; Ægn, Archean gneiss; pd, Pinto diorite; An, Algonkian, Neihart quartzite; Ab, Algonkian, Belt shale; Cm, Carboniferous, Madison formation; Dm, Devonian, Jefferson formation.

THE ORES.

General nature.—The ores of the Neihart district are all silver bearing, and a large proportion of them are silver-lead ores. In the product of one or two mines gold forms an important constituent. In most of the ores it occurs in quite insignificant amounts. The amount of lead varies in the product of the different mines. It averaged between 7 and 15 per cent in the shipments made from the principal mines for several years. In those mines producing the richest ores the amount of lead is too small to appear in the smelter returns. Zinc is present in all the ores, especially in those high in lead, and in the latter it often exceeds the 10 per cent limit allowed by the smelters. Copper is often present in small amount, and the richer ores also contain antimony and a smaller amount of arsenic. The veins show but a relatively small amount of superficial alteration and have yielded but little oxidized ores. The silver-lead ores are usually "basic;" that is, they are not siliceous, but have a gangue of carbonates. The rich, "dry" silver ores generally have a siliceous gangue.

Mineralogic character of the ore.—The common type of ore constituting the ore shoots of the Broadwater, Galt, Nevada, Moulton, and Queen mines and making up the greater part of the ore shipped from the district consists of an intimate mixture of galena and ankerite "spar"—a mixture of lime, magnesia, iron, and manganese carbonates with silica. There is also some heavy spar (barite), pyrite, and blende. The dry or rich silver ores consist of polybasite (locally called brittle silver), pyragyrite, and quartz, with small amounts of galena, pyrite, chalcopyrite, sphalerite, ankerite "spar," and heavy spar (barite).

ORE MINERALS.

Galena (lead sulphide, PbS).—This is the most common ore mineral of the vein, and it forms the bulk of the great ore bodies thus far mined. It occurs massive in the ore shoots, in disseminated grains and small masses through the lean ore. The massive ore varies in grain from fine to coarse, but it is seldom that the cleavage surfaces exceed a half inch across. Rarely the ore breaks into cubes an inch or less across. Galena also occurs in well-developed crystals with the quartz and other minerals of vugs. In some cases well-developed crystals one-fourth inch across appear coated with a soft metallic substance, and the mineral beneath is not so brittle as ordinary galena. Crystals lining recent water courses show a dull surface coated with an undetermined material. It varies greatly in silver contents, from less than 1 ounce up to 50 or more ounces per ton, and there seems to be no relation between the coarseness or fineness of grain and the amount of silver in it.

Pyrite (iron sulphide, FeS_2).—This mineral occurs in nearly every vein in the district, both in the quartz and in the altered country rock. It is as common as galena in most of the ores, but is usually most abundant in the poorer varieties. It occurs massive in the vein filling as well-developed crystals on the surface of vugs and disseminated through the altered country rock of the vein matter. It is commonly pale in color, and in the massive form is intergrown with blende and sometimes with galena. On the surface of vugs the massive form has a spongy, crystalline surface, though solid well-developed crystals also occur. In the altered rock of the vein filling and walls the crystals are minute, but perfect and of normal cubical forms.

Blende (zinc blende, sphalerite, ZnS).—Sphalerite is an extremely common mineral in all the veins. The common variety is dark brown in color and has a resinous luster. It occurs in all the veins and is closely associated with galena. It is always crystalline, but usually massive in the primary ore. Where it is of later formation it occurs in well-formed crystals lining the open spaces or vugs of the veins. Some of these crystals are honey-yellow or greenish yellow, transparent, and show lustrous faces. The massive variety is dark brown, sometimes almost black, and though it occasionally forms a considerable proportion of the ore constituting the big ore shoots, and increases the charges for smelter treatment, yet the miners regard it with favor, as it is currently believed to accompany rich ores. No tests have been made to determine whether it is silver bearing or not.

Polybasite (sulphantimonide of silver, 9AgS, As_2S_3, with copper and zinc replacing silver).—This contains 64 to 72 per cent of silver. The brittle silver of the Neihart miners is not stephanite, but polybasite, and forms a very important constituent of the ores, being the most common of the rich silver minerals. It occurs both as a doubtful primary ore mineral and as a product of secondary enrichment of the sulphide zone. As a possible original mineral it occurs in crystalline masses, showing a minutely rough fracture, and is without crystal outline. In color it is a steely gray and resembles gray copper (tetrahedrite). It occurs intimately associated with galena and blende in ore from the Big Seven, and with copper pyrite in the product of the Florence mine. It also occurs disseminated through the altered country rock of the vein matter in some of the other mines, usually in cobweb-like films on minute fracture planes. Its most important occurrence is, however, as a product of secondary enrichment of the primary ores. It forms well-developed crystals in open cavities, but the crystal faces are usually dull. Prof. S. L. Penfield, who has kindly examined for me the best specimen obtainable, has furnished me the following note:

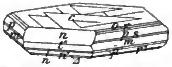

FIG. 54.—Crystalline form of polybasite.

> The crystals, owing to the uneven nature of the faces, were not well adapted for crystallographic measurement. They appear as 6 sided tablets, with triangular markings upon the basal planes, a development which is very characteristic for this species. This form is very close to that shown in fig. [54].[1] The material gave a slight reaction for arsenic and a decided test for antimony and silver.

In rare instances the mineral forms an open network of crystals whose surfaces are covered by a granular coating of a purplish and green iridescent substance of undetermined composition. In the smaller cavities it occurs coating quartz crystals, and as specks or minute crystalline aggregates on barite tablets or other minerals. In most instances, however, it occurs as crusts upon the original galena-pyrite ore in small open fissures, or filling minute fractures in this or the altered country rock. In such cases it is usually massive, rarely showing triangular terracing, more often coated by a sooty substance which is an extremely finely divided form of the mineral mixed with earthy oxide of manganese. It is the chief silver mineral of the Big Seven, Benton, and Florence ores.

Argentite (silver sulphide, Ag_2S).—This has been identified in mineral collections of the Neihart ores, but it is not a common constituent of them.

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[1] Copied from Am. Jour. Sci., 4th series, Vol. II, p. 24, July, 1896.

Stephanite (brittle silver, sulphantimonide of silver, $5Ag_2S$, Sb_2S_3).—This contains 68.5 per cent of silver when pure. This mineral, which was supposed to be of very common occurrence, proves to be quite rare, the material mistaken for it being polybasite. So far as known it does not occur in well-formed crystals.

Pyrargyrite (dark ruby silver, antimonial silver sulphide, $3Ag_2S$, Sb_2S_3).—This contains 60 per cent silver when pure. The dark-colored ruby silver is a common mineral in the rich silver ores. It is usually associated with polybasite, and in these ores is generally of secondary origin. It is found as grains scattered through vein quartz, and also in crystalline clusters, which rarely show well-formed crystals upon the surfaces of the vugs in the vein.

Native silver.—This is of common occurrence in the oxidized zone of the veins, and where the pyrargyrite has been subject to alteration. It occurs in the usual hair-like form, and as solid masses having a fibrous structure.

Gold.—Free gold is reliably reported from the Big Seven ores. The quartzite ores of this property contain oxidized molybdenum, but no mineral is visible to the eye.

Chalcopyrite (copper pyrite, $CuFeS_2$).—Some of the veins contain this mineral in rich ores, where it occurs mixed with polybasite. It is, however, of rather uncommon occurrence, and has not been noted in the ore extracted from most of the mines.

Pyromorphite (lead phosphate).—This has been observed in only one locality, a mine in Narrow Gauge Gulch, where it occurs in films and clusters of little crystals, coating a rusty iron-stained quartz. It is a bright yellowish green in color.

GANGUE MINERALS.

Quartz is an abundant mineral of the veins. It is generally coarse grained, slightly turbid or white, though not the typical milky-white quartz common in some districts. This quartz consists of interlocking grains, and quite commonly shows transition into a well-defined comb structure. In the cavities and lines of vugs, which are often found in the vein, it forms typical comb quartz. The ores also show small cavities lined with quartz crystals. All the other minerals occur as inclusions in quartz. In some cases the quartz coats a cryptocrystalline form of silica, which is best classed as chalcedony or opal, whose minute concentric banding and the frequent presence of a central nucleus of altered rock show its formation by metasomatic replacement of the country rock. This replacement of quartz and chalcedony is not prominent, however, though it is believed that the banding of the veins is in part due to such replacement.

Sericite (white mica).—This is extremely common in the altered country rock of the vein and its walls, but occurs in such minute scales as to be scarcely visible to the eye. It is this mineral which imparts the greasy feel to the altered rocks and which constitutes the chief constituent of the "clays" encountered in the mine workings.

Barite (heavy spar, $BaSO_4$).—This is a common gangue mineral, though not so abundant as the ankerite "spar" noted later. It is commonly a pure white, lustrous mineral occurring in tabular crystals in the richest ores or in massive form in poorer ones. The platy crystals sometimes form septate masses, with the interspaces filled by ore sulphides. In the drusy lining of vugs it occurs in pale-yellowish, well-developed crystals. A specimen from the Florence mine has been studied and figured for me by Mr. H. H. Robinson, under the direction of Prof. S. L. Penfield, of the Sheffield Scientific School of Yale University. Mr. Robinson furnishes the following notes:

> In the barite from the Florence mine at Neihart the habit of the crystals is tabular, which is common with this species, the basal plane *c* (001), the prism *m* (110), and the pyramid *z* (111) being the prominent faces. Faces of the brachypinacoid *b* (010), the brachydome *o* (011), and the macrodome *l* (104), although small, are almost always present, as shown by fig. [55]. On a few of the crystals the macrodome *d* (102) and the prism *n* (320) were observed, as shown by fig. [56], which represents the corner of a crystal showing these forms in combination with the faces *c*, *m*, and *z*, previously mentioned.

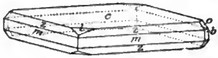

FIG. 55.—Crystal of barite.

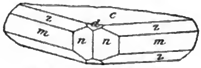

FIG. 56.—Crystal of barite.

Ankerite spar.—The most abundant gangue mineral of the ores is a white or very pale brownish or pinkish, coarsely crystalline substance which upon chemical analysis proves to be a mixture of lime, iron, magnesia, and manganese carbonates. In the small cavities of the galena ores, and rarely in the larger vugs, it is seen in rosette-like aggregates of small rhombohedral crystals, but no well-formed crystals were found available for measurement. Analyses of this gangue mineral have been made by Dr. H. N. Stokes in the laboratory of the United States Geological Survey. Analysis I is that of the pale-brownish or cream-colored material. Analysis II is of the white mineral.

Analyses of carbonate gangue mineral (ankerite spar).

Constituent.	I.	Ia.	II.	IIa.
Iron carbonate, $FeCO_3$	23.16	26.55	13.14	15.34
Manganese carbonate, $MnCO_3$	35.99	41.26	17.66	20.62
Lime carbonate, $CaCO_3$	13.16	15.08	36.84	43.00
Magnesia carbonate, $MgCO_3$	14.93	17.11	18.02	21.04
Insoluble in HCl	12.76	....	14.34	....
Total	100.00	100.00	100.00	100.00

The insoluble material consists of quartz and metallic sulphides. Recalculating the analysis and leaving out this impurity, we get the proportions given in Columns Ia and IIa.

The compositions given do not correspond to those of any one mineral species, but as siderite, dolomite, and rhodochrosite grade into one another, it is probable that the two minerals belong in this group. As the material is probably variable in composition, and may be a mixture and not a definite mineral species, the miners' name of "spar"[1] is used for it. In the lean ores it is the matrix in which the metallic sulphides occur. Both this spar and the mineral grains in it are cut by thin plates of heavy spar (barite) and by strings and films of quartz.

PARAGENESIS.

The association of the minerals with one another and their order and mode of formation constitute paragenesis. Each of the minerals found in the ore occur of different generations, and most of them not only as constituents of the original or primary vein-filling, but also of later formation, filling crevices and fractures. This is clearly due to recent circulating waters altering the original vein constituents.

The relative order of crystallization of the minerals is studied to the best advantage where the ores show successive "crusts" or bands of mineral, or where crystals of one mineral occur upon the crystal faces of another. The first arrangement is not usually well developed in the Neihart ores, but may be seen in several veins where the vein matter consists of fragments of country rock, cemented together by the vein filling. Similar crusts are also observable along vug lines, and even where the cavity is completely filled the crusted arrangement may be apparent. It is, of course, only in the open cavities that the crystals of one mineral are found upon the crystal faces of another. Where the vein minerals occur massive or show only poorly defined streaking it is often impossible to distinguish the order of formation by a study of hand specimens alone, and a careful microscopic examination has been made of thin sections of the ore.

In the primary vein-filling pyrite appears to be the earliest-formed mineral, followed by blende and galena. Specimens of crusted ores from the Big Seven mine are illustrated in Pl. LIV, *A*. While the ore is quartzose and somewhat different from the more common "spar" ores of the district, the order of mineral deposition appears to have been nearly the same in the different veins. The specimens figured show the following sequence of deposition, beginning with the oldest:

1. Quartz, radially fibrous, crystalline, with a little scattered pyrite.
2. Blende, with some pyrite; forming a massive layer.
3. Mixture of galena, pyrite, and quartz, with scattered grains of blende; showing rude banding; a little barite also occurs. Crystals of galena project into layer above.
4. Frosting of opaque white quartz in stout crystals. The pyrite crystals of No. 3 project up through this crust.
5. Polybasite, sometimes mixed with pyrargyrite. Filling of interstices between quartz crystals, specking on crystals (rarely good crusts).

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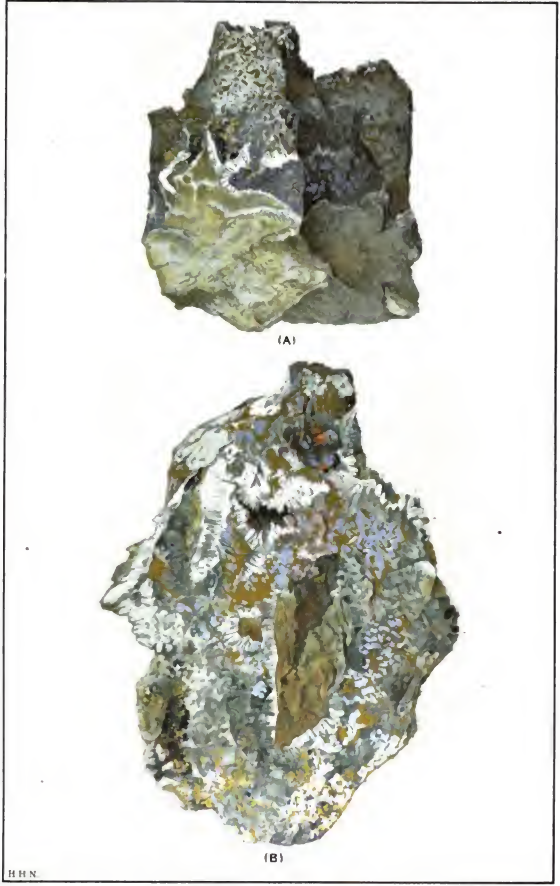
[1] Ankerite is a term used by some writers for such a mixture of carbonates, and this name is therefore adopted here because of its usefulness, although it is not the mineral ankerite.



JULIUS BIEN & CO. LITH. N.Y.

(A) CRUSTED ORE, FLORENCE MINE
(B) CRUSTED ORE, BIG SEVEN MINE

In other specimens the layer No. 4 is well developed and consists of quartz with masses of pyrite. In some cases the minerals form individual layers.

Fig. 57, which is drawn from a specimen of ore from the Big Seven mine, represents a cross section of the little quartz "vein" which constitutes the high-grade ore streak of the lode. The figure shows the relative abundance and association of the minerals, but does not represent the spongy texture of the polybasite and its intimate admixture with both galena and pyrite (chalcopyrite?), as this growth is too mossy to be represented well, and the mineral is therefore indicated as polybasite alone. The specimen seen in thin section shows ruby silver and polybasite intimately associated together and forming irregular, shreddy, and ragged patches. No positive identification of galena as the nucleus of such masses was made, but the association with galena is such as to indicate a possible change to polybasite. The pyrite is broken and fractured, but the grains are always sharply defined and no genetic relation to the silver sulphides is recognizable. A blende crystal seen isolated in the central quartz filling shows in thin section a crust of polybasite, the latter holding minute inclusions of pyrite, as shown in fig. 58. The blende seen in another section of such rich ore is invariably surrounded by a dark crust which is not iron oxide, nor does it appear to be an iron-rich blende. It is not definitely determinable, but resembles galena or a silver sulphide.

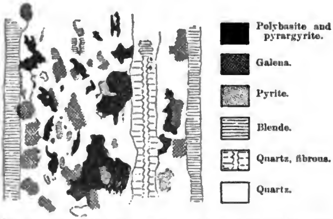


FIG. 57.—Diagram to show occurrence of minerals in quartz streak of Big Seven vein.

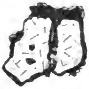


FIG. 58.—Crystal of zinc blende coated with polybasite.

Another little quartz vein an inch across, also in the Big Seven mine, shows walls of quartz radially arranged, with the center filled by irregular grains of blende and pyrite held in a quartz filling. The sulphides are seen to be parts of shattered and broken grains. The fragments, though separated by quartz, show faces fitting together, but more often are too much broken to show similar indentations. The blende was evidently formed before the pyrite, but continued to grow during the formation of that mineral, which is now seen in sac-shaped embayments in the blende and superimposed upon its faces. In general, the pyrite does not show crystal outlines, but the irregular form due to fracture and cleavage. The blende also shows fracture, but the borders have been softened by corrosion during the period of quartz filling.

An examination of numerous specimens from the Florence and Big Seven mines shows that while polybasite is possibly a constituent of the primary ore, its more common occurrence, like that of pyrargyrite, is as a secondary mineral, filling cavities and cracks in the original ore. The material gathered from the lowest level of the Florence mine shows polybasite in the form of crystalline tablets upon barite and other minerals, and also as a moss-like mass of open skeleton texture which seems to represent arrested deposition. The latter form is believed to come from a place in the vein where mineral-bearing water is now depositing this mineral, together with spar, quartz, and probably galena. Studied under the microscope the polybasite appears to be an alteration product of galena, and itself to be mixed with and to grade into pyrargyrite, which is in some cases its undoubted alteration product. It is certain that polybasite, as the important constituent of many of the ores, is of secondary origin. It occurs on all other minerals, and is itself not coated or dotted by them.

Thin sections show that the barite seen in the ore occurs in fractures of the original spar. Such fractures, cutting across spar crystals and shattering pyrite grains, sometimes show one part of the fracture filled by barite, with quartz filling beyond on the same line. In the little spar veins of the Ingersoll mine the metallic sulphides occur mainly in connection with quartz-filled fractures of the spar. Usually the barite is easily distinguished from the spar by the unaided eye, by its whiteness and its luster.

Sphalerite also occurs in well-formed crystals in some of the vugs, and is one of the most recently deposited minerals.

The products of superficial alteration—that is, oxidizing action—are those common to silver mines. The pyrargyrite alters to native silver, the galena to pyromorphite, cerusite, etc. These changes present no features of especial interest.

Summarizing the mineral composition and mineral associations of the ores, we find:

1. The common type of ore of the veins consists of galena and spar.
2. The rich ores of a few veins contain their chief values in polybasite and, more rarely, pyrargyrite.
3. The primary vein minerals are pyrite, blende, galena, and a mixture of carbonates called spar; chalcopyrite and in some instances quartz are of doubtful primary origin.
4. The above minerals all occur of secondary formation; that is, are later than the primary ore. The polybasite and pyrargyrite are of secondary origin. Barite is especially common in these secondary ores. Quartz occurs of several generations and is of latest formation.

VALUE OF THE ORES.

The values vary greatly in different veins and in the same vein. The galena ores, which form the bulk of the ore shipped, sometimes carry 60 to 70 ounces of silver and sometimes as low as 10 to 12 ounces. The average shipments of the Broadwater when the great galena ore bodies were being extracted was 40 to 50 ounces. Where the rich silver ores occur, as in the Florence, Benton, and Big Seven, the values run up very high—into the hundreds of ounces. The so-called high-grade ore of the Broadwater mine carries from 40 to 60 ounces of silver per ton; the low grade 20 to 30 ounces of silver and only traces of gold. Gold ratio of Big Seven, 5 ounces silver: $1 gold. The ores shipped by the Galt in 1897 ran 8 to 15 per cent of lead. Those of the Broadwater averaged 7 to 8 per cent lead while the large ore bodies were being stoped, but in 1897, owing to admixture of the altered country rock carrying films of silver sulphides, the amount of lead dropped to 2 to 3 per cent. In the early history of the district the ores from the upper part of the veins were exceedingly rich and values of $500 to $1,000 a ton were not uncommon. The ores now being mined vary greatly in silver contents. The galena ores carry from a few ounces up to 100 ounces or more per ton. In the lead ores the smelter returns show that the shipments rarely average over 35 to 40 ounces of silver per ton. The purest galena is sometimes very poor in silver. The richer ores also vary greatly in values, and no general figures can be given. The high-grade ores shipped from the Florence, Big Seven, and Benton mines gave returns varying from $3,000 to $4,000 a carload, which is approximately $200 a ton.

THE VEINS.

Occurrence.—The veins occur in a narrowly circumscribed area adjacent to Neihart, and traverse the gneiss and the various igneous rocks which penetrate it. So far as known they are confined to the gneisses and schists of supposed Archean age, penetrating in a few instances the quartzite which overlies those rocks. The geology of the area has already been described, so that here it will be sufficient to repeat only a brief summary of the leading facts. The crystalline schists of the Neihart district are composed of gneisses and schists of varying color and texture, in which various igneous rocks have been intruded as irregular branching stocks, as more regularly bounded intrusive bodies, and as dikes and sheets. The gneiss is roughly divisible by its mineralogic composition into white or gray gneiss, red gneiss, and black gneiss or amphibolite. The red and gray gneisses vary considerably in composition and texture, and it is often difficult to determine whether a particular modification should be classed as one form or another, as they occur intermingled. There is, however, a distinct banding. The intrusions are of several kinds and are all older than the veins. The Pinto diorite is the most common and characteristic rock of the district. It penetrates the gneiss without apparent order or system and is itself somewhat gneissoid in structure. The later eruptives are rhyolite- and granite-porphyries. The rhyolite-porphyry occurs in dikes and as bosses. The veins are independent of these eruptions also. There are no contact deposits.

Heavily bedded quartzites, inclined at an angle of 20°, dip southward from the borders of the district and form the base of a great series of stratified rocks. A few veins have been found in this quartzite on the summit of Long, Neihart, and Baldy mountains.

The ores occur in normal fissure veins, whose character varies in the different rocks traversed by the fissures, but which fill well-defined fissures in all rocks except the porphyry. In this the rock is shattered for a considerable width, and this belt of fracturing might be classed as a "crush" zone. The veins are primarily replacement deposits, with some filling of open fissures.

FISSURE SYSTEM.

As ore veins are fissures filled with ore, a knowledge of the structural relations of the fissures is of the utmost importance in mining, since the success or failure of the property as an investment depends upon it.

The vein fissures form part of a well-marked system of fractures traversing the rock complex. As described elsewhere, the gneisses are banded, the bands dipping to the south at angles of 40° to 65°. As this banding corresponds to differences in the character of the rock, it determines the nature of the outcrop. These rocks show a well-defined sheeting by a system of fractures crossing them at nearly right angles to the banding. This sheeting is not uniform throughout the district, as the fractures occur in groups or zones of sheeting. The fissures are not open cracks, but mere fracture planes recognizable in jointed surfaces of the outcrops, especially in the more massive rocks. Underground they are most often marked by thin films of ocherous or clayey material or by a distinct but almost imperceptible fracture in slightly altered rock. The fissures occur at different intervals; that is, the spacing between them is not uniform. Like those described in other mining districts, the sheeted zones are separated by rock showing little or no fissuring.

The vein thus has a sheeted structure, and consists of highly altered country rock inclosed by walls that practically limit the intense rock alteration. In some places such veins show areas where instead of sheeted country rock the vein matter is brecciated, the fragments being held in the finer breccia or cemented by quartz and other minerals. The width of the vein as thus defined varies greatly. It may be as great as that of the Galt vein, which is 60 feet or more between walls. Practically, however, the vein as worked seldom exceeds 8 feet in width. This sheeting is recognizable even where the original rock is entirely replaced, for the sheeting planes are often marked by comb quartz or vug lines, filling the original small open fissure. The hanging wall of the Ingersoll lode is sheeted, the fissure being 8 to 10 inches apart. In the Rock Creek vein the hanging wall shows five such planes in 5 feet. In both cases this hanging-wall rock is practically unaltered.

Course.—The fissures have a general northeasterly and southwesterly course. Owing to the difficulty of tracing them upon the surface, and the lack of an adequate base map, no attempt was made to map their outcrops. The maps of underground workings, so courteously placed at my disposal, show a course varying from true north to N. 45° E. The direction of individual veins is not constant, but the variation is not wide. The average trend is about N. 15° E. The vein fissures with but few exceptions dip west, the average dip varying between 60° and 65°, though there is considerable variation in the amount in different mines, and even in the same vein. The most extensive workings are those of the Broadwater mine. The map of the underground workings of this property (Pl. LVIII) shows the variation in the dip and strike of the veins in the different levels, and this may be considered as typical for the district.

Origin of fissures.—The fissures show the common features of compression fractures. Their occurrence in especial abundance at this locality is possibly due to a line of weakness first developed here in early geologic time, when this place was a shore line of a gradually deepening sea, or the hinge line of a strong flexure, which has at many times since been subject to fracturing, as shown by the numerous igneous intrusions. The fissure system to which the veins belong is, however, of later origin and probably coincident with the late dynamic disturbances of the region. When the range uplift occurred, the ore deposition followed a period of igneous activity.

Relation to dikes.—The fissures intersect dikes of rhyolite-porphyry in several mines. In the Galt workings the vein follows the general course of the dike which forms the immediate wall rock of the vein in some places, as shown in fig. 62, on page 427. In other workings the fissures cross the dikes at considerable angles.

Splits.—The fissures are approximately parallel, as already stated, so that several veins are workable from one crosscut tunnel. The vein fissures show, however, numerous "splits," or smaller fractures running off in the country rock of either wall, and these bear a definite relation to the course of the vein, forming the second set of fractures common where the fissures are compression faults. The vein walls are commonly quite well defined, and the crosscutting necessary in so many districts of sheeted rocks is not so essential here. (See note on Broadwater mine, p. 433.)

Effect of country rock on vein fissures.—The character of the fissure varies with the nature of the inclosing rock. In the red and gray gneiss it is a well-defined, clean-cut fracture; in the more schistose rocks the vein is wider and less sharply defined. In passing from gneiss into the Pinto diorite there is a pronounced narrowing of the fissure, the veins that are 5 to 8 feet wide in the gneiss contracting to 3 or 4 feet in the diorite, usually with a loss of ore.

In the rhyolite-porphyry masses of Snow Creek the vein splits up into a network of fractures, shattering the rock, so that a definite vein is not always recognizable. This is believed to be due to the brittle character of the rock, which is weakened perhaps by the strains developed in it in cooling from a state of fusion at the time of its intrusion. In ordinary weathering this rock breaks up into angular fragments which seldom exceed 2 or 3 inches across.

Where the vein encounters black gneiss or amphibolite it is commonly spoken of as faulted. In the instances observed no true faulting was recognized, but the vein was deflected as shown in fig. 60, preserving its normal course beyond. In this case the tough nature of the rock resists sharp fracture and becomes a curving break, narrower than in the feldspar gneiss and with less regular boundary planes. Observations were not sufficient to determine whether the vein was or was not slightly thrown by this band. The former superintendent of the Moulton, Mr. Frank Raymond, assured me that the vein of that mine, together with those adjacent to it, was cut through by a fault traceable southward to the Broadwater workings, and his observations upon the barrenness of the ores in the black gneiss, given in the account of the occurrence of the ore bodies, are pertinent in this place.

VEIN STRUCTURE.

Vein matter is the material which lies between the walls and forms the vein. It therefore includes various materials, the included fragments or horses of altered country rock, as well as the quartz and other ore and gangue minerals brought into the vein from the outside.

Vein filling consists of the material brought into and filling the open spaces of the fissure. It consists of ore and gangue minerals, those found at Neihart having already been noted. The difference between true vein filling and the altered country rock is an important one to bear in mind, since it is the former alone that constitutes the ore. In the Neihart veins the bulk of the vein material is frequently the altered country rock or the clays resulting from it. This altered country rock is often too much decayed to determine its original composition, but where nucleal masses are found the rock is seen to be the same as the vein walls. The intense alteration results in the formation of a material composed of white mica, carbonates, pyrite, etc. This material varies slightly in appearance according to the rock from which it has been derived, but is all essentially similar in composition. All traces of the original minerals have disappeared, and the only mineral recognizable to the naked eye is pyrite in small, well-developed crystals. Where the altered rock contains silver, the values are in secondary quartz and ore veinlets. The altered rock never constitutes workable ore unless such films of mineral are present.

Metasomatic replacement of the rocks has been, however, a very common phenomenon, and in the dolomitic gangue the altered rock is seen in various stages of replacement. The chalcedonic quartz resulting from so-called silicification of the country rock of the vein has also been noted.

Banding.—The Neihart veins show a prevailing banded structure. Very often this is plainly seen to be merely sheeted rock with the parallel cracks occupied by vein filling. More generally the vein near the productive ore bodies is more or less distinctly banded, but the appearance is due to a streaking of the ore minerals in the gangue. In the nearly solid galena there is often a decided banding or striping due to alternations of finer and coarser grained galena. In the usual ore composing the "shoots" there is a marked banding, due to alternate layers of galena and blende. The banding is also due to lines of spar, which are not persistent, and in the center of which there is often a line of cavities or vugs. Moreover, the spar itself is commonly spotted with grains of galena, blende, and pyrite, which show a general banded arrangement. Such banding is in fact a common and almost constant feature of the ore bodies, even the ore itself being banded when seen in cross section in the ore shoots. As a result of later fracturing, the ore shows lines of vugs or open fissures, but such places are more often partially filled, only the broader parts remaining open. It is about such cavities that true crustification is observed. Commonly the vein does not show a filling of successive crusts of mineral. Rarely the vein matter is a breccia of country-rock fragments cemented by filling, a structure that does not prevail throughout any one of the veins so far observed, but occurs in parts of several veins. The minerals about these fragments of country rock are arranged in concentric bands exhibiting true crustification, and open cavities between adjacent fragments are often seen. The stringers often show little veins of solid quartz, and such veinlets also occur in the altered country rock of the vein matter. This quartz generally exhibits a radial or comb structure.

Ribbon structure.—Secondary banding, due to a sheeting of the vein filling, as defined by Lindgren,[1] was rarely observed, but the ores exhibit a very plain secondary fracturing. The fractures cross the vein at a considerable angle, though they do not fault or very greatly disturb it, but merely crack it and leave minute crevices in part filled by later minerals. Where such fissuring of the ore is in parallel planes a banded structure is produced by reopening. These openings are usually small, are a common feature of the ore, and afford the opportunity for processes of secondary concentration of the silver sulphides.

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[1] Gold-quartz veins of California: Seventeenth Ann. Rept. U.S. Geol. Survey, Part II, p. 129.

ROCK ALTERATION.

The rock walls of the vein often show more or less sheeting and more or less chemical alteration. The amount of this chemical alteration is, however, quite variable along different veins, the zone of pronounced change varying from an inch or less to several feet in width. It is most pronounced in the rock material found within the vein walls and constituting the bulk of the vein matter. All stages of alteration are found in the vein walls, from the slightly altered rock to the light-gray or yellowish, soft, greasy, or clay-like material of the vein matter. All the rocks are subject to this alteration, even the Neihart quartzite. In the Pinto diorite it is less marked than in the gneisses, and apparently took place more slowly. The final product of alteration is very similar whatever the original nature of the rock, but in the less altered materials the former character is very often clearly recognizable.

The changes in the rocks are those common to the quartz veins of California,[1] being those due to the formation of carbonates, sulphides, and sericite. The changes are clearly those produced by metasomatic replacement. In studying the veins it is easy to distinguish between the quartz filling or "veins" deposited in open spaces and the altered country rock. The distinction is, however, of little use in most of the mines, since the ore occurs with carbonates. Although the varying composition of the Neihart rocks produces many local peculiarities, yet the general process of metasomatic alteration is that described by Lindgren.

The replacement of the altered rock by carbonates is recognizable under the microscope in slides cut from some of the vein rocks, and it is thought that the banded structure of the veins may be largely due to the replacement of the layers of sheeted rock by carbonates and ore. Tests have not been made to determine whether the pyrite of the altered rock carries gold or silver, but the general absence of other sulphides—except as fracture fillings—shows that the ores were introduced from outside when the carbonates were deposited.

DISTRIBUTION OF ORE IN VEIN.

Pay shoots.—In general it may be said that the ore streaks are very constant, but the values "bunchy." The ore minerals occur in nearly all parts of the vein, but are found concentrated in workable ore-bodies in only a relatively smaller part of the vein, such masses forming the pay shoots. Throughout the more barren parts of the vein the sulphides occur in streaks in the gangue minerals. Generally the ore bodies are composed essentially of galena with associated minerals. They occur in long, narrow, lenticular bodies, which as they wedge out pass into streaks; or they may end abruptly and another lens occur alongside in the vein, the end overlapping; but this, of course, varies in the different veins of the region.

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[1] Lindgren, op. cit., p. 146.

The occurrence of the ore bodies thus far developed in the Broadwater mine is shown on Pl. LX. The shoots have a general tendency to pitch northward. Mr. Raymond, the former superintendent of the Moulton mine, who made a careful study of the relationship of the productive ore bodies to the wall rock, found that, as a rule, the veins are productive where they traverse the feldspathic gneisses and are barren in the amphibolites and dark-gray gneisses. The Moulton workings, which tap three veins, show this relationship very plainly, and so far as I was able to extend my observations it is true for the camp, but the number of productive mines appears to me to be too small to afford data for a positive statement. The accompanying diagram (fig. 59) is intended as a plan of the area near the Moulton mine, on which the successive bands of gneiss are indicated, and the veins are shown in the order in which they occur, though for convenience their relative distances apart have not been preserved, the diagram not being drawn to scale.

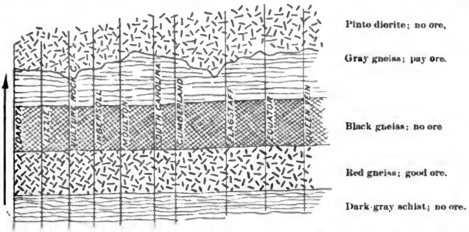

FIG. 59.—Diagram to show relative position of the Neihart veins and the relation of pay ore to nature of country rock. The veins are, for convenience, represented simply as straight lines.

Careful observations made in all the accessible workings show that thus far no workable ore bodies have been uncovered in the Pinto diorite. This is also true of the dense and very tough amphibolites, of relatively rare occurrence, which deflect the veins. As already noted in describing the vein fissures, these rocks narrow the vein, and the vein matter itself does not present the favorable physical conditions for ore deposition found in the other rocks.

Rhyolite-porphyry in dikes does not appear to show any association with the occurrence of pay ore. In the larger bodies the deposits so far worked proved very rich near the surface, but gave out in depth. The reason for this is discussed elsewhere. It is believed to be due to the spreading out, or, as it were, the diffusion, of the fissure in this easily shattered rock, so that the ores occur in numerous veinlets and films scattered through a considerable extent of rock, rather than in compact, well-defined ore bodies. The same shattered condition is, however, favorable to the penetration of later circulated waters and results in great surface enrichment, so that such properties show large amounts of such ores, as observed at the IXL, Eureka, and on Mackey Creek.

Influence of splits.—Stringers or splits generally enrich and often enlarge the ore bodies of the main vein, and near the vein the ores of such splits are themselves generally richer than those of the ore bodies of the main vein.

Permanence in depth.—The study of the region indicates that the fissures are deep. There is no reason to doubt that ore shoots occur in them at far greater depths than any yet attained. The rich silver sulphide ores peculiarly characterize the upper parts of some of the veins, and it is open to question whether such very rich ores will be found at greater depths. That they are of secondary or later origin in most cases in this district is beyond doubt, but these minerals are of primary origin in the California veins,[1] and may also be found so here.

CROSSCUTTING.

But few of the veins have as yet proved productive, though an unusual amount of prospecting has been done in the district. Crosscutting of the walls may be of value here, and one should always be certain that the wall is not a sheeting plane in the vein matter.

SUGGESTIONS FOR DEVELOPMENT.

A careful regard to the nature of the country rock, a close observance of splits or branches of the veins, and, above all, an exploration of the vein above those levels in which it is seemingly barren, are recommended. Past experience in the working of the veins shows that ore bodies have been overlooked because the shoots wedged out downward and did not show in the levels. The soft, altered rock of the vein is sometimes richer than the galena ore shoots, owing to minute films of ore, so that this rock should be carefully watched and assayed.

ORE DEPOSITION.

The observed facts of occurrence are believed to prove that the ores were deposited by ascending mineralizing waters, mainly in open cavities. Alteration of the country rock with metasomatic replacement took place at first along minute fractures in the rock and along cleavages in the minerals of the rock, the process being one of molecular substitution. The sheeted country rock between the vein walls was thus altered or partially replaced, as is well shown in specimens from the Florence mine. The metallic sulphides, if brought into the vein in sulphide waters, might perhaps be deposited by reaction between feldspar and sulphides,[2] which may account for the occurrence

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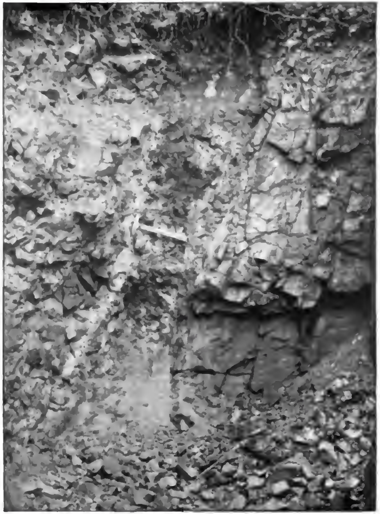
[1] Oral communication of W. Lindgren.

[2] See Kemp, Ore Deposits of the United States, New York, 1896, p. 34.



A. SURFACE CUT SHOWING APEX OF VEIN, EMPIRE CLAIM, NEIHART.

The hammer lies across the vein. Note the contrast between the weathered vein and the harder rocks on either side.

B. SAPPHIRE COULÉE, YOGO DISTRICT.

A hollow cut in limestone. The sapphire-bearing dike, which is on the right side of the view, runs in the direction of the gulch.

of the ore mainly in the feldspathic rocks. The original source of the metals is not known, but the presence of large intrusive bodies of ingeous rock (and the indications point to the existence of a general stock of such rocks underlying the district) affords a possible source of the metals at no very great depth as well as at no great distance laterally. The paucity of ore in the veins in the Pinto diorite itself indicates that the ore is not derived from this rock by lateral secretion.

It is believed that the primary vein filling is due to heated ascending waters, but no direct evidence showing that the waters were hot is at hand.

SUPERFICIAL ALTERATION OF VEINS.

Superficial alteration of the vein mineral by circulating oxidizing waters has produced small amounts of oxidized or carbonate ores, and these ores are found mainly along what appear to be even now the pipes or channels of descent for surface waters. Surface waters altered in character and robbed of their oxygen in their descent by the changes they induce in the metallic sulphides of the upper parts of the veins are believed to be the agents producing the rich sulphide ores forming secondary enrichments.

The outcrops of the veins do not show the great gossans or "iron caps" found at some localities. Surface alteration breaks up the vein matter in places and the quartz is rusty with iron oxide. The disintegration is, however, such as to make the outcrop rather inconspicuous on the débris-covered slopes. A view of a surface cut exposing the outcrop and upper part of the Empire vein is shown in Pl. LV, *A*. The planking seen on the right is an air box connecting with the underground workings. The vein, across which a hammer is seen, has sharply defined walls, and the contrast between the massive, unaltered gneiss on either side and the shattered quartz of the vein is very well shown.

SECONDARY ENRICHMENT OF VEINS.

Secondary enrichment has played an unusually important part in the development of the ore deposits of Neihart. The ores extracted in the earlier workings and those found to-day where new veins are opened all show silver sulphides deposited by secondary enrichment as crusts or crystals lining cavities, or as films or thin coatings along fractures of the primary ore, or in the oxidized zone as the so-called "sooty sulphide" ores that occur with manganese oxides. It is from this zone of enrichment that the high-grade ores, running from 200 to 1,000 ounces of silver to the ton, or even higher, were obtained in the early history of the camp. Although such ores played out in depth and caused many disappointments and failures, their occurrence played a most beneficial part in causing the development of the veins.

While the secondary enrichment of copper veins along a level between an upper zone of oxidation and the unaltered vein material below is a well-recognized fact, a similar enrichment of silver veins appears to have escaped general recognition. The secondary minerals recognized are chiefly polybasite and ruby silver, the former being more abundant. There are also bright metallic coatings, presumably argentite, on crystals and along fracture planes, and rarely in minutely crystalline masses. The chemical changes by which the primary sulphides split up and yield these minerals have not been investigated. The change is presumably the result of superficial alteration in which the primary vein minerals are broken up (chemically) and their silver contents are partially leached out and carried downward and deposited in the upper parts of the sulphide zone. Briefly stated, the process is believed to be a partial leaching out of the silver contents from the outcrop of the vein by surface waters and the precipitation of the silver at somewhat lower levels. The superficial alteration of the Neihart veins is not a marked one, as there are no great zones of carbonates and oxidized ore. Such ores occur only in limited amounts, being most abundant in the Broadwater vein, where the partially oxidized ores extend down 170 feet below the outcrop, and in pipes and along drainage fissures reach even greater depths. Generally, however, there is another zone of alteration below the level of these altered or highly altered ores—the zone of enrichment. These secondary enrichments are believed to be due to the alteration of argentiferous galena into the usual carbonates and sulphates, in which the silver and to some extent the other metals are taken into solution during the reactions produced by this alteration, the surface waters, changed in character by the formation of the lead carbonates, carrying the silver down and depositing it in crevices, open spaces, and minute fractures of the vein filling, especially of the metalliferous portions. The ore also occurs in the cracks of the shattered country rock, forming the vein matter where it is associated with secondary quartz. Very commonly the polybasite occurs in crystalline masses showing no definite crystal outlines. In the open spaces and vugs of the vein, crystallized specimens have been found associated with barite. It appears that this mineral is in process of formation at the Florence mine, 200 feet below the creek level, which is about the water line. It is possible, of course, that it may be due to the meeting of surface and of deep-seated waters. The zones of impoverishment, of enrichment, and of unaltered primary sulphides recognized in the case of copper veins are clearly present here, though the uppermost is of limited extent; and the zones are not so sharply or definitely separated from one another as they are in copper deposits, owing to the later fissuring of the vein filling allowing the secondary enrichment to be mixed with the unaltered sulphides. Polybasite is said by Dana to alter to stephanite and pyrite. In the Neihart ores this mineral seems to show an alteration to pyrargyrite and pyrite, and the former, in turn, changes to native silver in the upper zone.

SUMMARY.

The Neihart ore deposits occur in metamorphic gneisses of supposed igneous origin and Archean age, and extend upward into the basal beds of the Belt series of Algonkian age. They are sheeted fissures that cut both ancient and later igneous rocks and are believed to be of post-Cretaceous age.

The veins contain silver-lead ores; more rarely rich silver sulphides, and a value in gold of $1 to 5 ounces of silver. The common ores consist of galena, blende, and pyrite, in a gangue consisting of lime, magnesia, iron, and manganese carbonates. The rich silver ores consist of polybasite with a lesser amount of pyrargyrite and native silver in the oxidation zone; chalcopyrite also occurs. Barite is a common gangue mineral, but occurs in much smaller quantity than the carbonate "spar." The primary ore minerals are those mentioned above, excepting perhaps pyrargyrite. Polybasite more commonly occurs, however, as a secondary mineral.

The silver-lead ores vary from $20 to $60 per ton; the richer ores, from $100 to $200 or more per ton. The most valuable carload shipped by the Benton mine returned $36,000.

The fissures all belong to a single system, running about north and south magnetic, and dipping 60° to 80° W. The vein fissures are part of a general fissure system. The width of the fissure varies in the different rocks. It is widest in the softer schistose rocks, narrow but sharp cut in the massive diorite, irregular and narrow in tough and knotty amphibolite, and becomes lost in a multitude of little fissures in rhyolite-porphyry.

The veins are in part replacement zones of closely sheeted rock and in part filling of narrow open fissures. The rock between the fissures is intensely altered and decomposed, and the vein walls practically limit this alteration. The ores occur in more or less persistent streaks of spar, and rarely of quartz, in this altered rock or vein matter. The payable ore bodies occur in shoots. Secondary filling of open spaces by quartz has occurred in some of the veins, usually accompanied by rich silver sulphide ores.

Ore deposition was by ascending carbonated waters, producing metasomatic replacement along fissure lines. The veins have suffered later fracturing and secondary enrichment of the zone at or below the water level. There is now but a small amount of superficially altered or oxidized ore.

NOTES ON MINES OF THE DISTRICT.

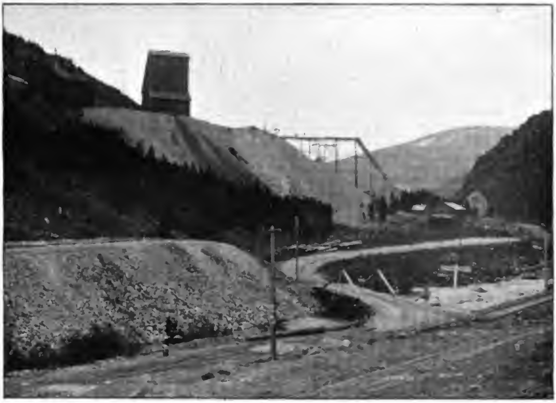
NEIHART DISTRICT PROPER.

Queen.—This was the first vein discovered in the district. It was opened by a tunnel driven a short distance on the vein, which showed such favorable conditions that the Queen claim, together with its extensions, the Homestake and O'Brien, was bonded for $45,000 in 1884. Further development work exposing less ore than was expected, the property was abandoned to the vendors the following year. Later development work by the owners resulted in the discovery of ore bodies from which large shipments have been made. The present development (1897) consists of a three-compartment shaft 300 feet deep, with 100-foot and 300-foot levels, and a tunnel driven 1,010 feet along the vein and extended several hundred feet farther by the owners of the Galt, who now work their property through this adit. The property is well equipped with machinery and buildings. A general view is given in Pl. LVII, *B*, showing the shaft house, ore bins, and waste dump.

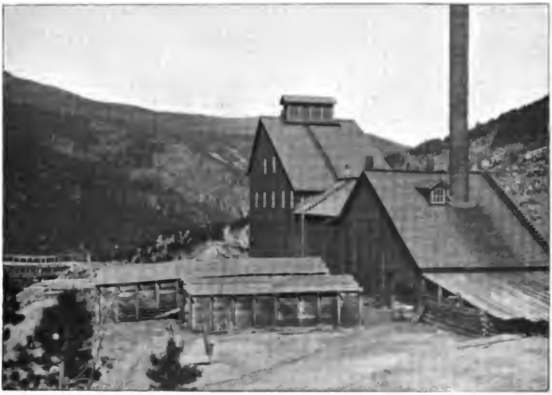
The Queen vein varies from 1 foot to 5 feet in width. The underground surveys show that the vein has an easterly dip, which is contrary to the prevailing dip of the other veins. The old shaft, 530 feet north of the entrance of the main tunnel, shows the vein to be vertical between this tunnel and the level 100 feet below, but to dip easterly at 80° below this. The levels driven from the new shaft show a less steep inclination, the angle being 80° above the 100-foot level and 75° below it. The pay ore of the early workings is said to have occurred in kidney-shaped masses scattered through the vein fillings, and not in regular ore shoots. As the mine was shut down and the shaft flooded at the time of the writer's visit, no personal observations were possible. The map of the workings shows that the vein at the shaft house has a general course of N. 20° to 30° E. The long tunnel which connects with the Galt workings has a course of about N. 40° E. There is reason to believe that it is run on a stringer or cross vein, for the O'Brien and Queen veins appear to be either the same or two closely adjacent parallel veins.

O'Brien.—This vein has been worked by a tunnel, which was over 420 feet long in 1896, and by a 324-foot crosscut from the main Queen tunnel to the vein. This surface tunnel and the drift from the crosscut show the vein to have a course of N. 10° E. and to dip west at the steep inclination usual in the district.

Mountain Chief.—This vein, on which the mines of that name are located, crosses the mountain spur lying between Belt and Carpenter creeks, from the London over the slopes to the Eighty-eight mine. The Mountain Chief mine was one of the first properties of the district to be developed. It was purchased in 1884 by the Hudson Mining Company for $18,000, and extensive development work at once begun, a concentrator and smelter being erected to treat the product of the mine. The ores first extracted were very high grade, it being reliably reported that over $10,000 worth of ore was extracted in sinking the first 20 feet on the southern shaft. This rich ore did not continue in depth, and as the low-grade ore did not concentrate well and a large amount of money was expended in driving the Eighty-eight tunnel without any returns work was stopped upon the exhaustion of the stopes of the upper tunnels



A. QUEEN OF THE HILLS MINE, FROM THE NORTH, LOOKING UP BELT CREEK.



B. QUEEN OF THE HILLS SHAFT HOUSE AND ORE BINS in 1890 and has not been resumed since. It is evident from an examination of the workings that the lower or Eighty-eight tunnel, though 1,700 feet long, is still several hundred feet from the vein, and that its course to the lead is not a direct one. The vein has a course of nearly true north and south, as shown in the upper workings, curving slightly toward the west in its southern extension. If, as is supposed, it is the same as the London vein, this change of course continues until, at the London workings, above Belt Creek, the course is nearly northeast. The dip is to the west, varying from 62° to 65°.

The property was visited in 1894, when the two upper tunnels were examined. The lower of the two tunnels is 950 feet above Carpenter Creek and is about 1,000 feet long. The vein traverses the Pinto diorite for the first several hundred feet, and in this rock is but a foot or so wide, the filling being a rusty oxidized material, showing no values at first, but carrying a streak of ore farther in. About 600 feet from the mouth of the tunnel the country rock changes and the vein widens to 7 feet across and carries an ore body stoped out to the surface. Two short crosscuts driven into the walls show the diorite to be quite solid, no sheeting being seen on either side of the vein. In the upper tunnel, which is about 700 feet long, the vein traverses "gashes" or included masses of the feldspar-gneiss in the diorite, and in part the vein appeared to have a Pinto diorite hanging wall, with gneiss on the foot, so that the gneiss seen on the hanging wall may be projecting tongues or wedges cut by the veins. A porphyry dike is cut at about 500 feet from the entrance. The vein, which is 30 to 40 inches wide, shows the ore shoot cut in the lower tunnel, which has been worked out. A crosscut from the upper tunnel into the east or foot wall of the Mountain Chief vein cuts a second vein 33 feet from it and another vein 10 feet beyond. The first vein cut is 3 feet across, but is barren of ore material; the second is only 2 feet wide, but shows a streak of good-looking ore.

Florence.—This has been one of the most successful mines of the camp, having been a steady producer since 1893, and thus far has shown pay ore in every part of the vein worked. The ore consists of a mixture of galena, pyrite, and blende, together with chalcopyrite, polybasite, and pyrargyrite. The vein runs northeast and is nearly vertical. Its width varies from 4 to 6 feet, and the fissure is always well defined. It traverses a gray feldspar-gneiss, generally much altered along the walls, and giving place to a black amphibolite for a short distance. The fissure varies in width in the different rocks, and in the amphibolite is deflected slightly, and narrowed, as shown in fig. 60, but continues its normal direction and width beyond this rock. The vein shows occasional splits or stringers, and where these run off they usually carry for short distances an ore richer than that of the main vein. The ore shows a well-marked banding, but it is more commonly a streaking parallel to the fissure walls, formed by a stringing out of the minerals in the gangue, rather than a definite crustification or banding due to alternating layers of different minerals.

The vein matter consists of leached and whitened gneiss, the richest ores being found where this alteration is most intense. This vein matter often has a fine sheeting or banding. The pay streak varies in width and in its position in the vein. In some places it fills the entire width of the vein, differing in this respect from any other vein worked in the district. The ore carries barite very commonly. The face showed in August, 1897, a 2-foot ore body averaging 60 ounces of silver to the ton. A section of the vein seen in the face of the upper tunnel on August 14, 1897, is shown in fig. 61. At this point a spur comes in from the west and enlarges the ore streak to 2 feet. The figure illustrates the banded structure of the vein due to the stringing out of the grains of ore minerals in the light-colored gangue. A line of vugs marks the center. The face figured in the diagram, fig. 61, shows an ore body decidedly above the average for the vein, both in width and in quality. The ore is partly brecciated, has vugs, and consists of white spar with some quartz, together with rich silver sulphides and galena.

The property is developed by two adit levels and a two-compartment shaft, 135 feet from the entrance of the lower level. This shaft is 300 feet deep, the bottom level being 280 feet below Belt Creek. In 1897 the lower tunnel was 465 feet long. Pl. LXIV, *B*, shows the ore and hoist houses and the entrance to the tunnels. The view also illustrates the characteristic weathering of the gneisses near by. The shipments for 1897 averaged 5 carloads per month. The claim has four well-defined veins in a width of 300 feet, only two of which have as yet been opened on the surface.

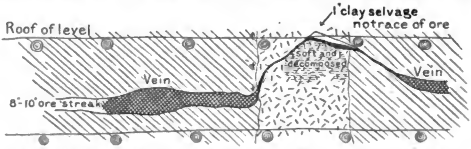
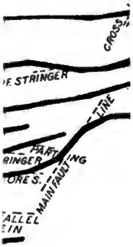


FIG. 60.—Fault where vein crosses amphibolite, upper level Florence mine, August 13, 1897

The Florence ore, as shipped, will not average 10 per cent lead, but the higher the silver the higher the lead contents. The poorer ores are carefully sorted before shipment. Very little stoping has been done on the upper part of the vein.

Concentrated and Monarch.—These properties now belong to the Florence Company. The former owners ran a 1,500-foot tunnel at a slight angle toward the Florence on a vein averaging 3½ feet wide. A crosscut at the end cuts a new lead, but no ore has been shipped from either vein.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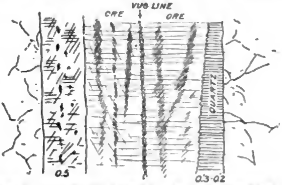


FIG. 61.—Face of vein, August 14, 1897; upper tunnel Florence mine. Width of vein 2 feet.

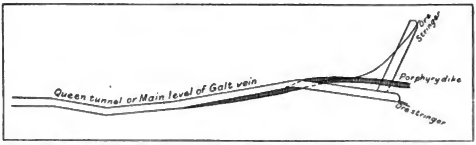


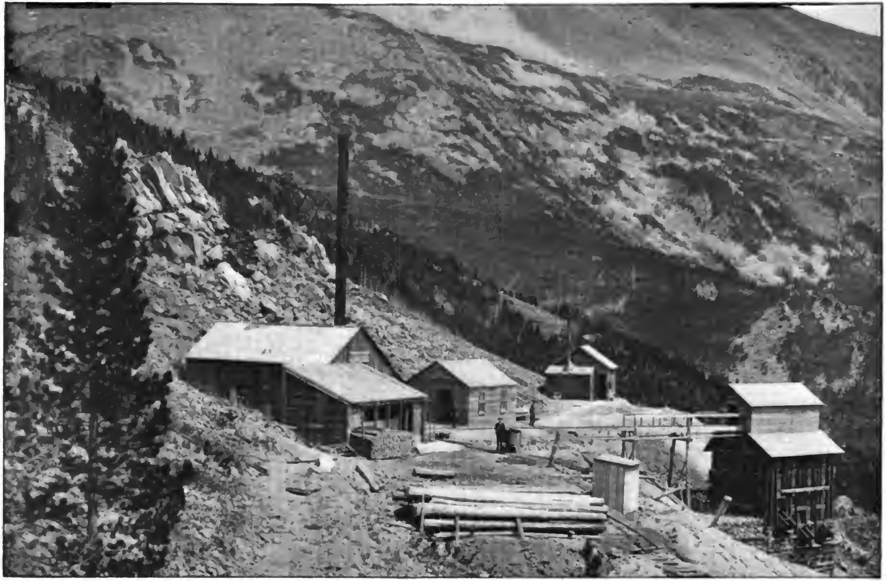
FIG. 62.—Diagram showing relation of Galt vein to porphyry dike, north end of Queen tunnel, August, 1897.

Galt.—This vein has been one of the large ore producers of the district since 1893. The Galt claim shows, it is said, four parallel veins, the Galt vein being the only one developed. It is now commonly regarded as the same as the Queen vein, though formerly the Equator, Galt, and Nevada claims were supposed to be on the same ledge. The vein has a course N. 20° to 30° E., and where the main ore body occurs is vertical, the dip being eastward to the north of the shaft and westward to the south of it. A light-colored feldspathic gneiss is the common wall rock, but in part the vein follows a dike of rhyolite-porphyry, the fissure cutting the dike and not being a true contact. Pinto diorite is seen in only one place in the workings, and black gneiss (amphibolite?) only in the fault at face of the level. The vein is 10 to 20 feet in width, but the vein matter is wider, and in the only places where the wall is cut through 60 feet of altered gneiss is encountered between the ore body and the unaltered country rock on the hanging-wall side. Crosscuts from the working level 150 feet above the Queen tunnel, and from the winze 150 feet below the Galt tunnel (150 feet above the other crosscut), show 40 to 50 feet of vein matter. It is certain, therefore, that the vein is a wide one. The rhyolite-porphyry is a hard rock, showing quartz grains in a dense, felsitic groundmass, and quite like the Neihart porphyry described elsewhere (pp. 375–376). The dike is 4 to 5 feet wide, and its relation to the vein is represented in the accompanying diagram (fig. 62), which shows its occurrence in the end of the Queen tunnel. The vein cuts the porphyry for a distance of 300 feet or more, and is seen forming one or the other of the vein walls, though not on both sides of the vein at one place; it also often forms horses in the vein. The same relation of vein and dike is seen in the Galt tunnel, 450 feet vertically above the Queen tunnel. Amphibolite or black gneiss was seen only at the extreme end of the lowest tunnel, where it faults or deflects the vein as it commonly does other veins of the district, but there is apparently also a true fault or slip cutting the vein at the face of the tunnel, as the ore and vein material are crushed and thrown to the northwest.

The ore is galena with the usual accompaniments of blende and pyrite, and occurs in a shoot that has been developed some 600 feet in vertical extent. The pay streak varies from 1 foot to 4 or even 5 feet in width throughout the workings. In the stopes visited the vein showed 2 to 24 inches of ore, separated by a seam of clayey matter from a porphyry foot wall. The ore has a gangue of spar. In the workings visited the ore showed a more or less distinct banding. The vein matter is largely an altered country rock, which is sometimes sheeted or shattered, and these minute fissures are filled with rich ore. The vein shows a clayey or talc parting, sometimes on both sides of the vein, but more commonly only on one wall. It is currently reported that the vein is richest where the gouge is most abundant. The vein has been developed by three tunnels. The middle or main Galt tunnel runs for 1,015 feet on the vein. A 150-foot shaft was sunk from this tunnel at 450 feet from the entrance. Pl. LIX shows the engine house and ore bins at the mouth of this tunnel as they appeared in 1895. Upon the extension of the Queen tunnel to the side line of the Galt claim, arrangements were made by which the Galt vein could be worked from this tunnel, 450 feet below the level of the Galt tunnel, the level being extended beneath the earlier workings. In 1897 two levels, at 75 and 150 feet above the Queen tunnel, opened up stoping ground, but the ore body had wedged out and the ore in sight was too low grade to warrant shipping. The mine was therefore shut down until early in 1899, when new development work disclosed good shipping ore.

Moulton.—This mine, owned by the Diamond R. Mining Company, was prior to 1893 the largest producer of the district, and it is credited with a production of 450,000 ounces of silver. The ore is galena, together with pyrite and blend in a barite and quartz gangue. The vein runs nearly north and south, and cuts bands of vari-colored gneiss. The vein dips 80° to 90° W., while the gneiss bands run east and west and dip 70° S. The vein matter consists largely of crushed and decomposed country rock, which is usually soft. No definite sheeting of this altered rock was observed, though it is commonly cracked and the joints are filled by ore. The vein is 3 to 7 feet wide, with walls of hard, unaltered rock. The pay streak is from a few inches to several feet in width, varying with the inclosing walls. Zinc blende occurs abundantly with the galena, and is looked upon favorably, for, contrary to the rule, it is here a sign of good paying ore, as the galena with blende carries more silver than the galena alone.

The workings show very striking examples of the influence of the



SHAFT HOUSE AND ORE BINS OF GALT MINE IN 1895; LOOKING SOUTH ACROSS ROCK CREEK GULCH.

country rock upon the vein, and the generalization made by the former superintendent, Mr. Frank Raymond, that the productive ore bodies occur only in the bands of feldspathic gneiss appears to be borne out by the workings of other mines. A fault is reported to run from the Queen of the Hills workings through the Moulton and across to the Broadwater. The development consists of a tunnel driven on the Ingersoll vein, which here runs through Pinto diorite and is barren of pay ore, with crosscuts to the Moulton and South Carolina veins. Pl. LXI shows the shaft house and mine buildings as they appeared in 1895. A three-compartment shaft 550 feet deep, with levels at 100-foot intervals, develops the lower part of the vein. The 300-foot level was the only one visited. South of the shaft it runs through black mica-schists, and is ore bearing in the pink gneiss, beyond which it passes into black gneiss again. To the north the level does not extend to the feldspar-gneiss. The mine is the only one where careful ore assorting has been done. The average smelting ore is reported to run 50 to 60 ounces of silver per ton.

Cumberland.—This vein is said to be an exception to the rule that the veins are ore bearing in the pink gneiss.

Ingersoll.—Over $45,000 has been expended upon this vein in driving exploratory tunnels in the unsuccessful search for ore. This expenditure was without doubt incurred because the ore carries a considerable proportion of its value in gold. Up to 1897 the total amount of ore shipped amounted to only 6 carloads, the last of which, though sorted, netted only $200 to the shippers.

The vein is a well-defined one, but in the five claims owned by the Ingersoll Company has been worked only on the Ingersoll claim. On this property it cuts both gneisses and Pinto diorite, as it crosses and in part follows the contact between these rocks. The gneiss is of both the red and the black varieties, and, as usual, in neither the latter rock nor the diorite does the vein contain any workable ore. Owing to the indented nature of the contact with the diorite, the vein cuts successive projecting tongues of the latter in the gneiss as well as the main body of the intrusion.

The vein has a course N. 10° to 20° E. The dip is to the west in the southern part of the workings, but at the end of the long tunnel is to the east, the angle of dip being from 60° to 80°. In the ore body from which shipments have been made the dip is nearly 80°, the vein showing an offset of 25 feet in the 111 feet between the two levels. The width varies with the nature of the inclosing rock. In the red gneiss it is over 2 feet; in the diorite it is commonly but a few inches, and nowhere does it exceed 1½ feet.

The property has been explored by two tunnels driven on the vein. The upper is about 150 feet long and exposes a small ore shoot; the face shows walls of hard and blocky rock, inclosing 30 inches of soft and whitened, much-altered gneiss that is sheeted by planes 6 to 10 inches apart. The ore occurs as a streak of sparry galena lying on the footwall, and as the vein rock is soft and clayey it slips easily in mining and caves down, leaving the ore attached to the foot. The wall rock in this tunnel is minette, but its nature was not recognized in the field and its relations are not known.

The lower tunnel follows the vein for 1,000 feet and then changes to a crosscut driven west to the Queen of the Mountains vein. The ore seen in the upper tunnel extends down to this level, and the shipments made from the property came from this shoot. In general, the tunnel shows the vein to carry a narrow streak of spar dotted with blende, galena, and pyrite, but averaging, it is stated, less than 6 ounces of silver to the ton. The diorite walls, which prevail beyond a point 700 feet from the entrance of the tunnel, show alteration for a distance of 3 or 4 inches.

About 1,000 feet from the entrance the adit level leaves the Ingersoll lead and for a little over 100 feet follows a cross fracture in the diorite, which has smooth and polished walls and occasionally films of rich ore. The diorite is very solid, showing no shearing until within 25 feet of a vein 2 feet wide and running parallel to and about 150 feet west of the Ingersoll. This vein carries bunches of 5 to 6 ounce galena.

One hundred feet beyond this vein the level leaves the fracture plane in the diorite and the course is almost due west till the Queen of the Mountains vein is encountered. These relations will be understood by reference to fig. 63.

Queen of the Mountains.—This vein has been explored for several hundred feet by levels run north and south from the end of the Ingersoll crosscut. The crosscut itself is driven entirely in diorite until within 40 feet of the vein, where a dike of rhyolite-porphyry is cut. This dike dips west toward the vein at 45°. The north level of the Queen of the Mountains vein shows a narrow streak of spar dotted with blende, pyrite, and galena, but no workable ore bodies. The level driven south from the crosscut tunnel was filled by a cave-in at the time the mine was visited, but it is said to be cut in black gneiss and to show no workable ore.

Ingersoll No. 2.—The property is developed by tunnels run north on the Ingersoll vein. About 1,000 feet from its mouth the lower tunnel is deflected and is cut across the country rock for 600 feet in order to crosscut the veins parallel and adjacent to the Ingersoll on the west (see map of workings, fig. 63). Throughout this tunnel the Ingersoll vein shows only 2 to 3 inches of lean ore, and by some of the miners is believed to be a "stringer," meaning an offshoot that runs parallel to the vein.

In the crosscut at the end of the long tunnel the rock is a very hard, solid, unaltered Pinto diorite, breaking with blocky fracture, and is very hard to drill. It shows no sheeting or fracturing until within 25 feet of the 300-foot east crosscut, where a stringer is seen having

NO. 4
TH
NO. 6 LEVEL
EVELS.
LEVEL SOUT

smooth polished walls, the fracture running nearly west and dipping north. This crosscut shows a 2-foot vein carrying bunches of solid galena that holds but 5 ounces of silver per ton. This cross lead is followed 100 feet or more, showing occasional films of rich mineral, but no bunches of ore, though bunches of quartz occur in the hard rock.

Rock Creek.—The three veins supposed to cross this property have not been sufficiently developed to prove their value. The workings comprise a tunnel with several branches. The Rock Creek vein pitches west at 60°, is 2½ to 12 inches wide, and runs through blackish or dark-gray gneiss holding much reddish gneiss and shot with tongues, stringers, and bunches of Pinto diorite, similar to that seen on the surface workings. The ore thus far extracted yields, when sorted, 16 to 18 per cent of lead, with 80 ounces or more of silver per ton. It shows galena with silver sulphide and some wire silver, and carries no gold. The workings throw little light on the vein structure. The west branch has a spur or offshoot to a stope from which the rich ore was being taken out and runs through Pinto diorite mostly. The east branch follows a narrow fissure showing a film of spar without any pay ore, running through solid gneiss, the face showing leached and whitened gneiss. A little offshoot from the vein shows the hanging wall to be a solid, blocky, black gneiss that is distinctly sheeted with five sheeting planes in a thickness of 4 feet, but as there is no talc or decomposed rock along the sheeting planes they are not prominent. These planes adjoin 6 to 8 feet of shattered gneiss.

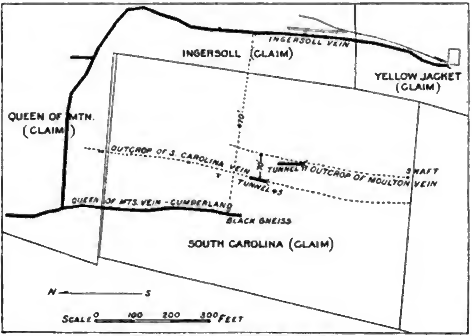


FIG. 63.—Workings on Ingersoll vein, 1897.

Lizzie.—This property is developed by numerous surface cuts and a short tunnel. There are supposed to be four veins in the claim, two of which are cut by this tunnel, the easternmost being the Lizzie vein and Lizzie No. 2, the vein parallel to it. The surface cuts show a vein of brown, ocherous, oxidized ore, containing residual masses of galena. This ore carries no gold. The tunnel, which starts near the end line of the claim, is 200 feet long and shows at its face a vein of white spar and quartz but a few inches wide. The ore occurs like a string of lenses edge to edge. The wall rock is solid and blocky in fracture and is largely amphibolite, in which shearing is not prominent. Higher up the hillside is an 80-foot tunnel. The discovery shaft is 73 feet deep.

Lizzie No. 2.—This vein is developed by two tunnels, 110 and 120 feet long. The first carload of ore shipped was from the discovery shaft, and netted $786 for about 15 tons. Up to 1897 the claim is estimated to have produced about $5,000 worth of ore.

Dakota.—This property is said to have a good showing of low-grade ore in a well-defined fissure. In 1897 the workings were not accessible, the tunnel being filled by a cave-in about 300 feet from the entrance. This lower tunnel starts in the Pinto diorite, but the wall rock changes to black amphibolite-gneiss, and in a short distance this is replaced by the diorite again. No vein was observed in the 300 feet

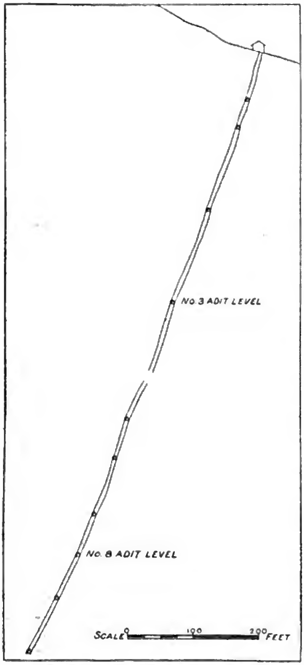
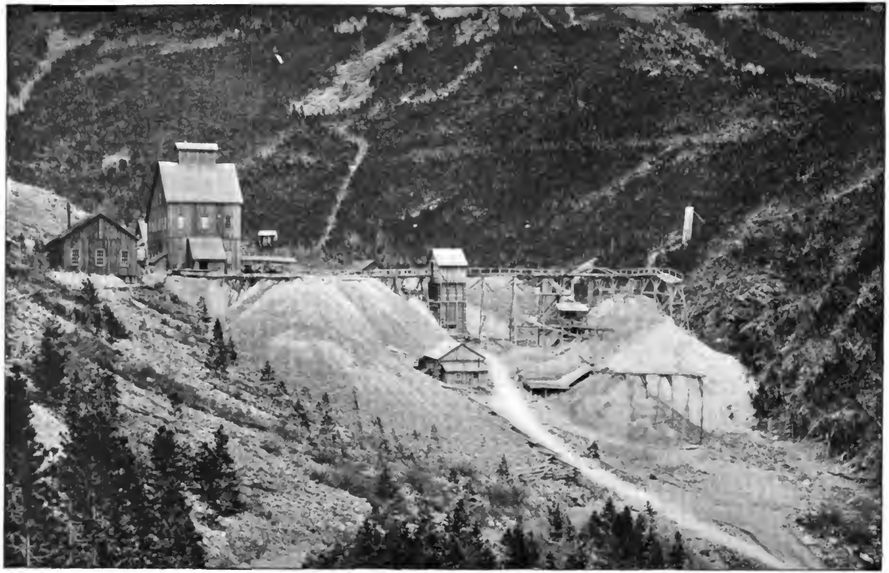


FIG. 64.—Cross section of Broadwater vein.



MOULTON MINE, 1895.

In Rock Creek Gulch. The claim lines show as light lines where timber has been cut out on slopes.

accessible in this tunnel. The lead is said to be 4 feet wide. The dump heap shows a leached white gneiss impregnated with pyrite.

Broadwater.—This mine has been the chief producer of the district since 1893. The property embraces several adjoining claims situated on the upper slopes of Neihart Mountain, southeast of the town, and from 700 to 1,000 feet above Belt Creek (see Pl. LXII). The property was actively prospected in 1885, employing as many as 75 men at that time, but the ore bodies then found were not considered to warrant further development, and work was abandoned and the mine shut down. In 1892 the property was sold for $165,000, and the new owners at once began extensive development. Large bodies of argentiferous galena were at once encountered, and the mine yielded over 1,000,000 ounces of silver in the succeeding two years, the net profits being stated to have been $465,000 up to 1895. In December, 1896, the ore in sight was largely exhausted and a long adit tunnel seemed to limit the downward extension of the ore shoots, but further development uncovered new extensions, and the mine has since then continued to yield a steady output of ore. The shipments averaged 3 cars per week from January to July, 1897, and were then increased to 15 cars per week (300 tons).

The vein has a general course of N. 26° E. and dips west at angles varying between 60° and 80° (see fig. 64). The vein has been, owing to its productiveness, more extensively prospected than any other in the district. Pl. LVIII, which shows the workings in 1896-97, gives a good idea of the regularity of the vein in lateral extent.

The vein is strong and well defined and traverses light-colored schists and reddish or streaked gray feldspathic gneisses, which it crosses at nearly right angles throughout the greater part of its extent as developed. At the extreme northern end the level penetrates Pinto diorite, and no paying ore has been found in this part of the vein. Near the entrance to the lower tunnel sheeted gneissoid porphyry is found. In the Pinto diorite the vein is well defined and continues with unaltered course, showing a banding of rusty and bluish clay, and occasionally small bunches of lead ore, though in the diorite it has nowhere yielded any paying ore bodies. The vein varies in width in different parts of the workings, averaging between 3 and 6 feet. It has been explored for over 1,000 feet vertically and 2,400 feet in lateral extent. Offshoots or splits are numerous, mostly from the hanging wall, but are not large or important. In the upper workings the vein splits about a horse of country rock 50 feet wide and 100 feet long. Small horses 50 feet in length and half this in width are sometimes encountered. The workings indicate a splitting of the vein southward.

The foot wall is usually well defined. The ore sometimes occurs "frozen" to it, but is more often separated by a band of clay a few inches thick, which sometimes is a rich ore, owing to films of silver sulphides. No streaks or slickensides were observed on either wall. The hanging wall is usually a hard though little-altered rock, but crosscuts are few and its character is known only at such places.

The vein shows usually a very distinctly banded structure. This is not due to successive layers or crusts of gangue and ore materials, but chiefly to a sheeting of the altered country rock which lies between the vein walls and constitutes the greater part of the vein matter. This material, of which the waste-dump heaps are formed, is a greatly altered leached gneiss or schist. In some parts of the mine the vein matter is brecciated, fragments of country rock being cemented by barite and quartz with ore minerals, and to a lesser extent by clay. No evidence showing the amount of faulting was obtained. In some parts of the workings the vein is about 4 feet wide and shows 3 to 8 inch ore streaks near both walls, with intervening altered country rock sheeted in plates one-half to 2 inches thick. As the ore itself is sheeted in this case and the minute fractures are coated with secondary pyrite, it is evident that post-mineral fracture has occurred here, as it has in several other mines of the region.

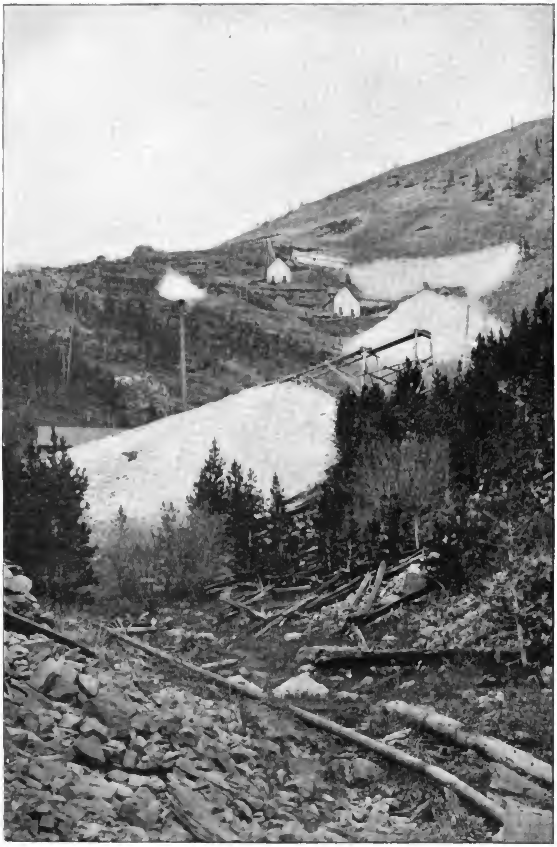
Two faults are observed. The first is noted only on the lower level, and throws the vein to the east in its southern extension. The second is near the north end of the workings, and is a well-defined slip with dip of 50° N., and is marked by 6 inches to 3 feet of soft clay or slickenside materials between hard country rock. The fault cuts off the pay ore, but the vein continues beyond it with unaltered course into the Pinto.

The ore consists chiefly of galena, together with a little pyrite in a gangue of spar, with lesser amounts of barite and blende. The shipments often averaged 20 per cent zinc, 7 to 8 per cent lead, 40 to 60 ounces of silver for the high-grade and 20 to 30 ounces of silver for the low-grade ores. In 1897 the ores contained only 2 to 3 per cent of lead.

The vein generally shows first a streak of soft, muddy material, from a few inches to a foot thick, resting upon a well-defined foot wall. Upon this is the sulphide streak, consisting chiefly of galena, then a low-grade ore, which is a mixture of spar, heavy spar, and galena. The hanging-wall rock is commonly hard and unaltered, but in some parts of the vein the reverse is true.

While the galena ore bodies do not commonly show a sheeted or banded structure, yet in some parts of the vein this structure is very marked, and even in hand specimens the ore shows a decided banding, due to minute layers of spar running through the galena. There is also a coarser banding, due to alternations of sparry ore with nearly pure galena. The ore is soft and easily broken and handled, one man averaging a carload (20 tons) every two days. The decomposed rock between the vein walls carries large amounts of carbonates, and the wall rocks also contain carbonate minerals.

Fig. 65 shows a cross section of the vein observed on stopes below the third level near the south end, and illustrates a common appearance of the vein. It is impossible, however, to give a general section, as the vein varies from point to point. While the ore minerals occur rather



BROADWATER MINE, 1895.

Quartzite debris slide seen on right, above dump heaps.

generally disseminated throughout the sparry parts of the vein, the pay ore occurs in shoots. Pl. LX shows the space stoped up to December, 1896, and illustrates the size and dip of the shoots.

These shoots are often persistent for many feet laterally, but vary somewhat in position in the vein. They vary from narrow streaks to lenticular bodies which are sometimes as much as 4 feet across. In the southerly workings, near the entrance, the ore occurs in isolated and well-defined lenses whose ends overlap. The best ore bodies consist of a nearly solid mass of galena with a little barite, and will average 40 ounces of silver. The ore above the No. 3 level (6,416 feet elevation) was largely oxidized, showing residual bunches of galena. This surface oxidation extends several hundred feet or more below the outcrop, and is deeper along pipes or water courses. The richest ores are not the galena ores, but those carrying silver sulphides, which occur in the upper workings. In later development work at lower levels the sheeted vein material, which is a bleached and altered gneiss, is reticulated with minute films of silver sulphide, so that this rock, resembling waste, is more valuable than the galena-ore streak. In one place the vein for 18 inches nearest the foot wall is sheeted, and shows a streak of poor galena ore but 6 inches across, that carries much spar and holds but 4 to 5 ounces of silver. The rock above this for a width of 5 feet is netted with cobweb-like films of blue sulphides, so that the rock as a whole carries over 300 ounces of silver. This rock seems to fade into the country, and no good hanging wall was observed. Near this same place the vein passes into a greenish gneiss, and is filled by a coarse breccia of this rock held together by spar, the foot wall being a solid and blocky red gneiss and the ores low in zinc. Zinc-lined water courses were observed in a number of different parts of the mine. The workings are wet, owing to the surface openings, but are well drained by the lower adit level.

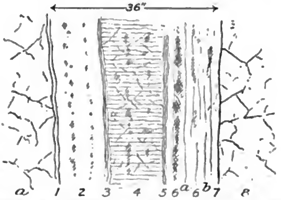


FIG. 65.—Face of Broadwater vein, on stope below No. 3 adit level, under blacksmith shop. *a*, wall rock; 1, ½″ black clay; 2, white spar and stipple mineral; 3, clay gauge and fault clay; 4, rusty shattered spar and some mineral; 5, 3″-5″ black talc with best values; 6^a, ore streak; 6^b, soft blue rock and good ore; 7, wall; 8, blocky rock, showing iron-stained face.

In many places where the vein is not workable it shows a mass of spar peppered with grains of galena and pyrite. As shown in the map of the workings, the property has been developed mainly by adit levels. The relative elevation of these levels and the appearance of the surface works of the mine are well shown in Pl. LXII. The property is admirably situated for the use of a wire-rope bucket line, but the ore has been hauled down a very steep wagon road—the lowest level being 400 feet above the railroad—despite the fact that the teaming bill for six months more than equals the amount necessary to have built a bucket line.

SNOW CREEK MINES.

The veins found upon the north slope of Long and Neihart mountains cross the slopes drained by Snow Creek. Though not over 2 or 3 miles from Neihart, they are accessible only by wagon road up Carpenter Creek, and the long haul and rough roads make the mining of low-grade ore impossible under present conditions. Thus far no large bodies of silver-lead ores have been found, but the high grade character of the ores mined has led to extensive development work. The veins cut the various rocks of the district, and the nature of the country plays an important part in the economy of the mining development. A large number of claims have been prospected, but the only productive mines are the Benton group, Big Seven, and formerly the IXL and Eureka. The Cornucopia has, I am told, been extensively prospected, but has not been a large shipper.

Benton group.—This was for many years the largest producer of high-grade ores of the camp, and the gold contents were so considerable that the mine was profitably worked from 1892 to 1896 despite the general depression in silver properties. The property consists of twelve claims, situated at the head of a southerly fork of Snow Creek under the western point of Long Baldy (locally known as Neihart Baldy). The only workings visited in 1893 were those of the new tunnel or uppermost adit of the mine. These workings nowhere cut entirely through the vein, exposing the walls. The vein matter is a bluish decomposed gneiss carrying pyrite. The ore, though but a few inches in width, was very rich, consisting of loosely compacted sulphides with native silver. The hanging wall of the tunnel, which is driven on the lead, shows Pinto diorite, and the foot wall a quartzose gneiss, but the vein crosses both rocks and is not a contact lode.

In the summer of 1897 the high-grade ore bodies of the vein were reported exhausted and active development work was suspended, though a couple of leasors were extracting some galena ore from the stopes near the face of the lower tunnel. The workings were visited, but were very wet, and the ore bodies were obscured by mud in most places. The main adit level is 2,400 feet long and is driven on the vein. In this lower tunnel the vein is from 3 to 6 feet wide, and shows walls of both gneiss and Pinto diorite, the former prevailing where the ore shoots occur and the vein pinching to a few inches in width in the latter rock. The vein is a breccia or gneiss, which is in places checked and sandy, but more generally is altered to a soft clay-like material, so that the mine workings are wet and muddy. The Benton ore has been unusually high grade, the values being chiefly in gold, with some silver; but the bodies at the end of the new tunnel consist of lead ore, generally zincky and low grade. In the third tunnel the vein carries ore in bunches and not big shoots. In the main lead the values were largely in gold. The tunnel is said to cut two leads. The ore produced in the past has been much like that of the Big Seven. One carload netted $26,000, according to Mr. D. C. E. Barker, and the total product of the mine had exceeded $400,000 in 1898.

IXL and Eureka.—This mine is developed by a 250-foot shaft and levels, but has been idle for several years. The ore obtained in the upper workings was very rich, but gave out at 90 feet below the surface, the vein consisting of rock checked by minute fissures and not showing a single well-defined fissure. This is the general experience in mining the ore deposits of the district which occur in porphyry. In the writer's opinion this is due here, as it has been found to be elsewhere in the State, to the physical nature of the country rock. The porphyry is fractured by a close jointing, fissuring the rock so that it was freely penetrated by the mineralizing waters, and the ore, instead of being confined to a well-defined vein, is disseminated in minute films throughout the fine joint fissures of a wide zone. Secondary enrichment of such deposits generally results in the concentration of the minerals near the surface as rich ores, which are probably silver sulphides—"sooty" sulphides they are called in some camps. They contain much manganese oxide, and are quite unlike those sulphides found at greater depths in the neighboring mines.

Big Seven.—This mine has been for several years past a large producer of the rich silver sulphide ores, carrying high values in gold. The company owns a group of seven claims upon the high mountain slopes north of the summit of Long Baldy. The ore being extracted in August, 1897, when the mine was visited, carried from 100 to 500 ounces of silver and $50 per ton in gold. The mine was producing from 2 to 3 carloads a month of 300-ounce ore, derived from development work alone, no stoping being done. The veins are exposed by numerous surface cuts and by three adit levels. The veins have the general northeast course common in the district, and are well-defined fissures, cutting gneiss and a dike-like mass of Pinto diorite. Their upward extension is in the overlying Neihart quartzite. The vein dips west at a steep angle, and is from 5 to 6 feet wide (except in passing through the Pinto diorite, where it is 3 inches to 2½ feet in width). It carries a 1- to 2-inch streak of white quartz spotted with sulphides, which sometimes forms good ore; the rest of the vein matter is altered country rock cased in hard walls. There are often two ore streaks, but they are not persistent, though one is always present. The hanging-wall streak is 1 to 6 inches wide, and occurs "frozen" to the wall. The vein widens 700 feet from the entrance to the tunnel, and has a correspondingly wider streak of quartz and ore. At the face it was 12 feet wide, and a lens of ore on the foot wall was 1.8 feet wide. The hanging-wall ore streak was not exposed, as the hanging wall was not cut. The vein matter is a decomposed gneiss, which appears crushed, but shows no recognizable sheeting, and it is impregnated with quartz spotted with ore.

The Big Seven ore shows polybasite with ruby silver and the usual baser sulphides. It carries very little galena, and is generally regarded as a dry ore. This ore presents a wider variety of structure than the ore of any of the other veins. In the smaller quartz streaks the ore consists of quartz, with galena, blende, and pyrite as primary filling, showing banding and comb structure. The larger masses show much barite in a crisscross structure, the interspaces filled by pyrite, galena, and blende, which along vugs is capped by massive galena, with chalcopyrite at top, covered by quartz crystals. Replacement of country rock is seen in some specimens, but more commonly there is a sharp demarcation between altered country rock and filling, which is best seen in the breccia ore.

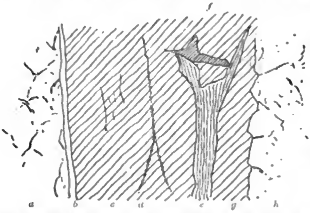
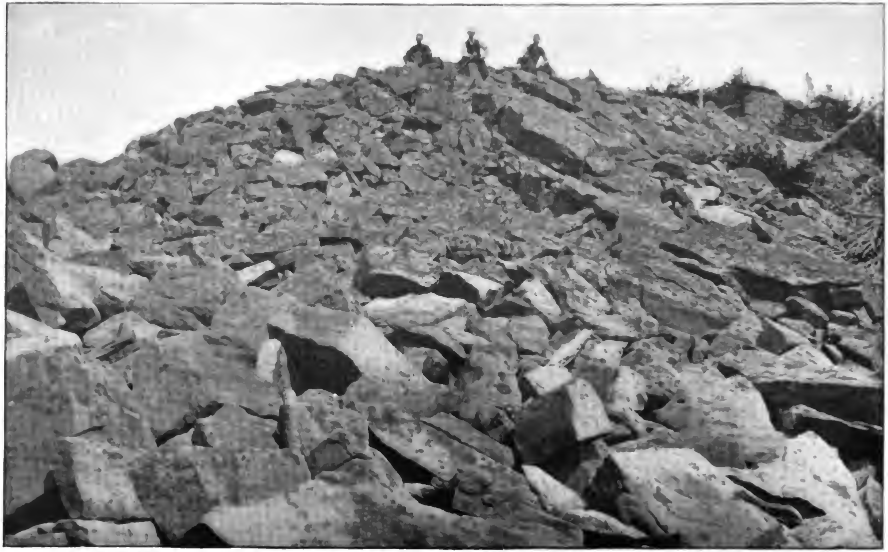


FIG. 66.—Big Seven vein in quartzite, face of upper drift, August, 1897. *a*, quartzite, somewhat fissured and checked; *b*, 3 inches of white clay; *c*, cracked and fissured, rust-stained quartzite, carrying gold; *d*, $\frac{1}{2}$ to $\frac{3}{4}$ inch of soft clay; *e*, soft white clay; *f*, brown sand; *g*, quartzite ore; *h*, unaltered quartzite.

An unusual type of ore found here consists of zinc blende with a little pyrite and galena, coated by plumose quartz whose surface is dotted with masses of pyrite, the ore being evidently formed along a vug line. A carload of this ore ran, zinc 28 per cent, silver 800 to 900 ounces per ton, gold $150 to $200 per ton. The owners say that the smelter returns do not give any lead from the Big Seven shipments, though the average ore always contains more or less galena visible to the eye and determined as such by the usual tests. The ratio of the gold and silver contents of the Big Seven ores appears to be about $1 in gold to 5 ounces of silver.

The most interesting feature of the mine is seen in the upper workings, where the vein passes into quartzite. In the only face seen the vein runs N. 20° E., is nearly vertical and is 7 feet wide, and showed the cross section given in fig. 66. The upper workings were inaccessible, owing to a snowslide a few months previous to our visit. From information furnished by the owners and from the character of the veins in quartzite on the neighboring claims, it appears that the vein scatters in the quartzite and is very irregular. There is reason to believe that rich ore deposits will be found along the contact plane between the gneiss and quartzite, where the veins pass into the latter rock. Samples of the oxidized rock assayed by Prof. C. E. Monroe for the



SUMMIT OF NEIHART MOUNTAIN.

Showing character of quartzite talus and bedding plane of the rock laboratory of the United States Geological Survey gave 49.75 ounces of silver and $145 in gold per ton. The quartzite ore is in part a quartz filling and in part impregnated quartzite. It shows no free gold, and no mineral other than a rustiness of the rock due to iron oxide is observable even in ore that assayed $1,600 per ton, but the ore is shown by chemical tests to contain a large amount of molybdenum. The average ores from veins in quartzite yield 20 to 50 ounces of silver and $5 to $10 in gold per ton. A sample collected by the writer from a ledge (not located) on the head of Narrow Gauge Gulch, on the opposite side of the mountain, gave, upon assay by C. E. Monroe, $4 in gold and 12.20 ounces of silver per ton.

In addition to the Big Seven mine there are a number of properties located upon working veins in the quartzite. The rock is very dense and hard to work and forms large talus blocks, as seen in Pl. LXIII, showing the summit of Neihart Mountain. The rock dips southward at about 30°, the bedding plane being seen in the illustration. The summit of this mountain shows a narrow but well-defined vein of rusty quartz, whose course is N. 80° E., dip 85° N. It is uncovered by a trench 50 feet long and 5 to 6 feet deep, from which a low grade of ore has been taken. Other claims on the saddle between Neihart and Long Baldy Mountain, or east of it and a little higher than the Big Seven workings, show short tunnels that expose rusty ores of cemented quartzite fragments carrying $5 to $10 in gold and 20 to 50 ounces of silver per ton. Rich quartzite ore like that of the Big Seven has not been found in quantity in any of these claims.

MACKEY CREEK.

The discovery in 1897 of veins carrying rich surface ores along the course of this stream brought into prominence a part of the district that had been generally regarded as barren. Several claims were located on the two veins now known as the Gold Rock and the Phillippi. The first named has a nearly north-and-south course, like those of the district generally, and is nearly parallel to the creek, whose waters in some places flowed over the lead. The veins all occur in the Neihart porphyry. This rock forms the ridge between Mackey Creek and Carpenter Creek, but shows few exposures, though the débris covers the ground. The exact areal extent of the rock was not determined, owing to this débris and to the dense growth of lodgepole pine that everywhere covers it. The workings seen in 1897 showed only bunches of ore in a checked and shattered porphyry.

A fissure showed in the face of the Golden Dream, the lead having a course N. 20° E. and dipping 60° to the west. The surface cut seen showed a shattered and altered porphyry streaked with brown and black manganiferous ore. A short tunnel on this property showed no distinctly defined vein at its face, but an altered rhyolite-porphyry netted by fractures marked by reddish films carrying pyrite and some quartz.

The Phillippi lode, from which some rich ore was being extracted, was at that time opened for only 100 feet, and the ore occurred on the contact between a hanging wall of dark-gray micaceous schist and a foot wall of altered porphyry. The Mackey Creek ore bodies illustrate the branching or diffusion of the vein fissures in the porphyry. Everywhere that prospect cuts or drifts had been run some ore was seen. The ores are all secondary sulphide enrichments. Some nucleal masses of galena were seen, and a very little oxidized ore, but the greater part consisted of sooty-looking sulphides mixed at the grass roots with manganese oxides. As was stated in discussing the influence of wall rock on the character of the vein fissures, the porphyry is favorable for such surface ores, but the veins are not to be relied on in depth. The ores will undoubtedly change in depth to galena, with or without silver sulphides. Until development work shall prove them permanent the deposits found in porphyry will be looked upon as likely to decrease in both value and quantity in depth.

At the head of the creek the Dawn and Foster lodes have been developed by drifts several hundred feet in length. The ores thus disclosed were low in grade and zincky, though there is a well-defined vein with quartz filling along a porphyry-gneiss contact. Pl. LXIV, *A*, shows this property. Specimens of nearly pure galena from this claim have been assayed for the laboratory of the United States Geological Survey by C. E. Monroe, and prove very low in grade, carrying but 0.15 ounce of silver per ton.

The Whippoorwill mine, shown in Pl. LXV, *A*, was one of the earliest discoveries of the district, but has never been a profitable producer. It is easily accessible by the Carpenter Creek wagon road, and the recent discovery (1897) of ore bodies on the claim by leasers has revived interest in this part of the district.

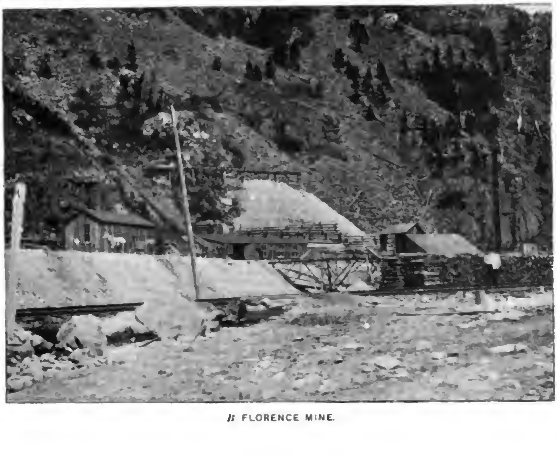
HARLEY CREEK.

Mention should be made of the Harley Creek prospects, although they were not visited. The writer is indebted to E. K. Abbott, of Neihart, for the following notes: The ore samples from these prospects carry as high as 12 to 20 per cent of copper, with a few dollars per ton in gold. The Imperial group, comprising eight claims, was in 1897 developed by a 450-foot tunnel, the Royal by a 200-foot tunnel, and the Granite Mountain by a 225-foot tunnel on the vein.

HOOVER CREEK.

Claims located about the head waters of Hoover Creek yield low-grade auriferous silver-lead ores, but the prospects are not sufficiently developed to show their character.

A. MACKAY MINES (DAWN AND FOSTER CLAIMS), HEAD OF MACKAY CREEK.



B. FLORENCE MINE.

by the Helena Smelter Company, and if energetic work is prosecuted, so that development work keeps ahead of ore extraction, the future of the mines seems bright.

OCCURRENCE OF THE ORE DEPOSITS.

The ore deposits of Barker may be divided into two classes: First, those occurring in veins in the Hughesville syenite; second, those found in limestones along contact planes between limestone and porphyry (fig. 69). The Barker and the Wright and Edwards mines belong to the first class. The second class includes a number of very productive ore bodies—the Carter, May and Edna, Tiger, Moulton, and other mines. Experience with several of these ore bodies having shown that the galena changes in depth into low-grade pyrite, it is a question whether this is a common phenomenon with deposits of this type. A plan and section of the Carter mine are shown in fig. 67. The May and Edna, Silver Belle, and Carter mines show the same phenomena.

In this connection, also, may be noted the fact that the Cumberland, the greatest ore body of the Castle Mountain district in this State, is a pipe of galena in limestone. Here also the ore changes in depth into pyrite, at a point where the fissure is occupied by a porphyry dike that does not reach into the upper working. The workings at the Tiger and Moulton mines may not be deep enough to show whether the galena will be replaced by pyrite in depth, though the ore body of the mine is cut at 326 feet below the outcrop and is still a good grade of galena.

In the Tiger the ore bodies near the surface were relatively flat and shallow, indicating a spreading out along joints and bedding planes, but as the rocks are much fissured and the structure is complicated at this point, no definite evidence showing their exact occurrence was obtainable in the short visit made there. The mines located upon ore bodies in the syenite itself appear, however, to be upon well-defined fissures in the syenite and include the oldest mines and largest producers of the district.

NOTES ON THE MINES.

Barker.—This and the Gray Eagle are the oldest mines of the district and yielded large amounts of ore in 1881, 1882, and 1883, and again in 1891. The mine is situated on Galena Creek, a short distance above the town of Hughesville. The vein is in the Hughesville syenite, the mine being near the contact with granite-porphyry. The ore is an argentiferous galena mixed with pyrite and a little chalcopyrite, in a gangue carrying calc spar and some barite. The syenite close to the vein is much decomposed and the granite-porphyry encountered in the workings is leached and altered to a soft, white, crumbly mass. The main body of syenite is fresh and very hard, though traversed by films of pyrite. The workings were not accessible in the years when the district was visited. The mine was leased in 1898. The property

A. WHIPPOORWILL MINE, CARPENTER CREEK, NEIHART.

B. MOUTH OF CARPENTER CREEK, NEIHART.

Gorge cut in gneiss and Pinto diorite.

includes the Barker, Gray Eagle, and Equator claims, and is developed by a two-compartment shaft, with levels and a tunnel.

Wright and Edwards.—This mine is also one of the oldest of the district, and one of the best producers. It is developed by a shaft said to be 250 feet deep, and is therefore the deepest mine of the camp. The vein is a well-defined fissure in the Hughesville syenite, which in part follows the contact with a trap dike. At the time visited the mine was closed down and only the tunnel was accessible. This is cut through the solid syenite, running in an easterly direction for some 300 feet before reaching the lode. The syenite shows in this distance eight or ten well-defined parallel fracture or sheeting planes that run northeast and southwest, or parallel to the vein, and also very slight reticulation by cross fractures. These planes are marked by a few inches of leached and whitened rock, but so far as known have not been prospected. The trap dike is 20 feet wide, and where seen seems to form the west wall of the fissure. This rock, as described in the previous chapters, is a kersantite. The syenite is so decomposed and leached near the ore bodies that it slacks in part to clay when exposed on the dump. It contains much pyrite in stringers and disseminated grains.

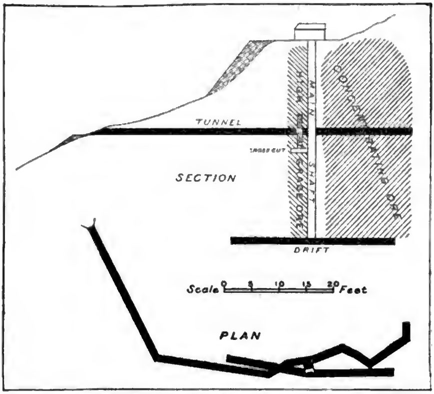


FIG. 67.—Plan and section of Carter mine, Barker district.

The vein is said to average nearly 3 feet in width. The ore is like that of all the mines—an argentiferous galena—and occurs mixed with pyrite and zinc blende. Samples of the best ore seen showed 40 to 50 per cent of lead and 30 ounces of silver per ton. It shows banding and crustification and evidences of formations in open cavities, and occurs in well-defined sheets separated by ore streakings or a low-grade ore. The property includes the Power, Neptune, and Joe Hill claims, all patented, and in 1898 was bonded by T. C. Powers et al. to the United States Smelting and Refining Company as a source of supply for the Great Falls Smelter. In 1897 the shaft was 180 feet deep, with the usual levels, and a tunnel was expected to tap the shaft at 300 feet. The mine was shipping in 1897.

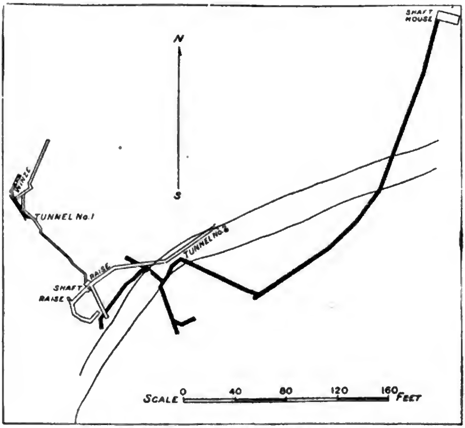


FIG. 68.—Workings of May and Edna mine, Barker district.

Paragon, May and Edna, and Carter.—These mines are on or near the Kibbey divide, where the wagon road from Barker and Hughesville to Kibbey and Belt crosses the mountains. The workings are in the Carboniferous limestones on the flanks of Clendennin Mountain, where the strata are upturned and intruded by sheets of rhyolite-porphyry. The workings were inaccessible when visited in 1894 and 1897. The Paragon is developed by a 150-foot shaft, and is said to show 2 feet of ore. Like similar deposits in limestone, the ore occurs in chambers or bunches. The May and Edna was the principal producer in the early history of the district.

Moulton, Tiger, and T. W.—These mines form a group in the gulch between Mixes Baldy and Clendennin Mountain. The first two are said to be on the same vein, which is in the broken and folded limestones near the contact between the porphyry of Clendennin Mountain and that of Mixes Baldy. In the workings visited in 1894 the vein appeared in one place to have rhyolite-porphyry or Wolf porphyry on one wall, and to be in Barker porphyry.

The Tiger has been a shipping mine for many years past, and was worked even when the other mines were closed down. The ore is argentiferous galena, which occurs in lenticular bodies, those seen in the workings in 1894 being lenses 3 to 6 feet wide, pinching out rapidly in depth. The workings at that time comprised a 335-foot tunnel and shaft. According to information since received, the tunnel has been extended to 550 feet, the shaft has been deepened to 120 feet (1898), and an ore shoot 3 feet wide and carrying 30 to 40 per cent of lead, with 18 to 20 ounces of silver per ton, has been developed. The property has been worked under lease by various parties since 1893, during which time the shipments of ore aggregate about a thousand tons, in shipments of 10 to 20 carloads a summer.

The Moulton mine, comprising a group of four adjacent claims, viz, Harrison, Bellfont, Pioneer, and Moulton, has also been a shipping mine for several years past. The ore is a galena, carrying from 20 to 40 ounces of silver per ton. It is developed by a 100-foot shaft and a tunnel, completed in 1898, which tops the lode when 1,232 feet long, at a depth of 356 feet. This level shows a vein lying, it is said, on the contact between a porphyry hanging wall and limestone. The ore body opened by this adit shows a galena that is 7 feet wide in places. Three thousand tons of ore were shipped in 1898. The last ore body discovered is said to be 14 feet wide.

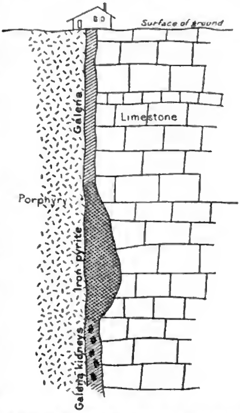


FIG. 69.—Ideal transverse section of type of contact ore deposits, Barker district.

Liberty and Queen Esther.—These mines are situated in the syenite-porphyry, near its contact with the granite-porphyry mass, whose highest point is the peak known as Mixes Baldy.

The Liberty lode has a course N. 60° to 65° E. and dips at 50° to 60° to the south, into the mountain. The ore is the usual argentiferous galena, and occurs in a banded mixture with quartz. The pay ore occurs in a shoot that is 3 to 4 feet wide and 130 feet long, where it is cut by the upper tunnel. The mine is developed by two tunnels driven along the vein, 110 feet apart, and an inclined shaft 190 feet deep following the vein from the surface to the lower tunnel. The ore shoot was not crossed by the lower tunnel when the mine was visited in 1897, but was cut for 90 feet. Its vertical extent was still unknown. At that time there were 30 men employed and from 2 to 3 carloads of ore a week were shipped. This mine was also reported leased to the United States Refining and Smelting Company in 1897.

The Queen Esther mine shows a quartzose vein carrying a pay streak of galena up to 6 inches in width in a well-defined shoot. The vein, like the Liberty, dips into the mountain, and at nearly the same angle. The vein follows in part along the contact between syenite and a granite-porphyry dike which forms the east face in the lower tunnel. In 1897 the vein was developed by two tunnels, one of 95 feet and one of but 75 feet in length. Four carloads of ore were shipped in the summer of 1897.

Other claims.—The McKinley was worked in 1898, the development work consisting of a 95-foot shaft, which shows a 3-foot ore body of galena and spar, and from which samples were reported to assay 40 to 60 per cent lead and 90 to 120 ounces of silver per ton. This property was not visited. The St. Louis was not visited, but is said to show a vein carrying an ore running 44 per cent lead, 20 per cent zinc, and carrying 37 ounces of silver per ton. It is developed by a 200-foot tunnel. The Blackhawk, Ontario, Defiance, and Sunlight claims are reported to be promising, but no information concerning them was obtainable.

MIDDLE FORK OF JUDITH RIVER.

Several discoveries of copper, silver, and gold ores have been made in the region drained by the head-water branches of the Middle Fork of Judith River. On King Creek one such property shows an oxidized ore carrying gold, which occurs in the limestones beneath an intrusive sheet of trachytic porphyry. A small amount of the ore was treated in an arrastre run by water power, but no work has been done for ten years past.

The Fairview claim also shows a body of low-grade silver-lead ore, along a contact between a porphyry sheet and limestone.

The Grendal claim has yielded ore carrying copper as well as lead, picked samples assaying 10 to 12 per cent of copper and $5 in gold, according to published statements in the local press. The development consists of a 75-foot adit tunnel and a 50-foot shaft.

YOGO MINES.

HISTORY.

The discovery of gold in the alluvial gravels of Yogo Creek brought the customary stampede in 1879. The town of Yogo was started, and during its brief period of life is said to have contained 1,200 or 1,500 people, with well-built log houses and the usual accompaniments of a mining town. An active season's work, during which several miles of ditches were built and considerable amounts of gravel passed through the flumes, was followed by a clean-up so meager as to discourage further operations, and the boom collapsed. The town was all but deserted in 1883, and in the many years that have since elapsed the log cabins have been carried off by settlers to the treeless country of the Judith Basin, until to-day a half dozen or so are all that remain to mark the spot. The locality was visited in the summer of 1889 by G. E. Swallow,[1] at that time State inspector of mines. In his report he states that at the Weatherwax mine, on Skunk Creek, he found a small mill having a crusher, Hunter oscillator, and Frue vanner, working 6 to 15 tons of ore a day, the ore coming from the Gold Belt mine and yielding $15 per ton. Four men were employed at the mine and mill together. An arrastre, run by an overshot wheel, was also running at Yogo on ore from the T. C. Power mine. In 1893 a dozen or more men were living there. In 1897 only three or four men were in the neighborhood.

The alluvial gravels, though too poor to pay a return in the early days, have been worked at intervals ever since, though never by more than half a dozen men at a time. In 1897 but two men were thus employed, and they informed me that they made fair wages from the little strip of hillside gravel they were then washing. Panning a little of the gravel, the gold was found to be bright and clean, without quartz, rather rough, and in flattish grains; no scale gold being noticed.

During the single season of its existence Yogo was the center from which prospectors streamed out over the neighboring region in every direction. Many discoveries of minerals were made at this time and in subsequent years, when both Great Falls and Neihart contributed men who diligently sought for mineral deposits in this part of the Little Belt. Much work was done—seldom wisely—in this vicinity, but, so far as the writer has been able to ascertain, the total production of the mines at Yogo proper does not exceed one or two thousand dollars. The Weatherwax mine is reported to have yielded as much as this, but no definite information on this point could be obtained. On Running Wolf Creek two mines, the Woodhurst-Mortson and the Sir Walter Scott, have produced considerable ore, which was freighted to Great

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[1] Reports of the inspector and deputy inspector of mines for six months ending November 30, 1889, by G. E. Swallow, inspector, and J. B. Trevarthen, deputy inspector: Journal Publishing Company, Helena, Montana, 1890.

Falls, but definite returns could not be obtained. Several prospects have also yielded small amounts of silver-lead ore from Running Wolf Valley and Lion Creek.

GENERAL OCCURRENCE OF ORES.

The ores of the mines at Yogo proper are generally very low grade or occur in deposits too small to work. Galena, pyrite, chalcopyrite, and their oxidation products are the chief minerals. The deposits occur in the altered limestones at or near the contact with the granular rocks of the Yogo stock or the sheets and dikes connected with it. The "stock" contact can be very easily traced by the prospect pits, whose dump heaps of white marble are common features of the contact zone. The minette dikes cutting the limestones have also been quite often prospected, as their contact is frequently marked by bands of pyrite. The under contact of intrusive sheets of porphyry is also very often mineralized. There is a widespread mineralization, but, so far as developments show, the ore is too low grade to be workable under present conditions. The ores at Yogo which have been worked occur beneath intrusive sheets of porphyry, the ore being a replacement of the limestone and in part an impregnation of the leached and altered porphyry itself. The cursory examination made of these properties does not enable me to say what their future may be. Geologically, their occurrence is a favorable one. It is perhaps safe to predict that the oxidized ores found in several localities may yield a profit by the cyanide or some equally cheap process of extraction.

The south contact of the Yogo stock was located for a distance of 10 miles, being known as the "blue lode." So far as known, no ore has been shipped from any of the workings. At the head of Yogo Creek a prospect shaft near the trail shows decomposed lead ores and a rusty gossan, said to be slightly auriferous. West of Yogo Peak an old log shaft house stands on the contact between the main shonkinite mass and the altered limestones. No ore was seen here, but the dump heap shows shonkinite carrying stringers and films of pyrite. The northern contact of the stock has also been more or less prospected, but without success. The Lion Creek prospects (Judith mining district, unorganized) are on porphyry contacts some distance from the syenite mass.

NOTES ON INDIVIDUAL PROPERTIES.

The following notes were obtained during brief visits to the district in 1893–94, though few workings were accessible, and the few facts presented are given for the reason that no other information whatever is obtainable.

Quaker City and Della.—These claims are situated on the open slopes of the basin at the extreme head of Elk Gulch. At this place the Carboniferous limestones are fractured and show numerous sheets of syenite-porphyry, which are similar to, and probably offshoots from, the main mass of the mountain top. Dikes of dark minette are also seen. The claims have been worked intermittently since 1892, several shallow prospect shafts, one 40 feet deep, being sunk, and a tunnel several hundred feet long driven into the mountain side. Ore, said to contain free gold and to assay well, is reported to have been found in bunches, but I have been unable to find that any of it has been shipped, and the samples gathered by myself and assayed for this office carry too little value to be classed as ore. When last visited—1897—the writer was informed by the placer miners that the claims were no longer worked. When visited in 1893 the owners, Charles Ferris and M. R. Dornblut, were driving a tunnel on a dike of minette. The shaft showed 5 to 6 feet of mineralized material said to be low-grade ore, but the ore body was cut off by porphyry. The tunnel was at this time about 300 feet long. The minette being soft and easily mined, it was followed, though the so-called ore was but a band 2 to 3 inches in width that was found at the contact of the dike and encasing limestones. The course of the dike is northeast and the dip 70° W.; the trend is not constant, but somewhat sinuous. The limestones (Cambrian?) occur in layers 3 to 6 inches thick, with shaly portions, and show contact metamorphism alongside the dike, where they are altered to marble and a coarse aggregate of garnet, pyroxene, and calcite. The ore streak occurs with a thin clay selvage, which is not always present along the contact plane. The so-called ore, found at both the tunnel and the shaft, is pyritous, and of too low grade to work, picked samples gathered by the writer giving no gold and 0.05 ounce of silver as a result of careful assays made by C. E. Monroe.

California.—This claim is situated on top of the ridge at the head of Skunk Creek, near the contact between the syenite and limestones. The vein matter is said to be 10½ feet wide, to have been developed for 50 feet in depth, and to carry $7 per ton in gold. It is owned by the Judith Valley Mining and Milling Company and is worked by Louis Pepin, R. Giroux, and Joseph Sutler.

Christopher Colombo.—This is the name given a prospect on the Bandbox Mountain side of the divide, at the head of a fork of Wolf Creek. The workings comprise a 500-foot tunnel, a 75-foot shaft, and two crosscut levels. The lead shows only silver-lead ore, occurring in nearly flat beds of limestone.

Weatherwax.—In the early eighties, when the Yogo district looked most promising, this property was extensively prospected and a 5-stamp mill erected. The workings embrace tunnels driven into the slopes west of the gulch and tapping a lode said to be a contact deposit between limestone and a porphyry sheet. It was not accessible when the district was visited.

T. C. Power.—This claim is on a sheet of porphyry showing on both sides of Skunk Creek and on Elk Creek. Considerable prospecting has been done at various periods. The ore is a rotted, oxidized quartz, showing no minerals, but said to carry low values in gold. A minette dike cuts across the claim. The property has yielded several hundred tons of oxidized ore, treated in the Yogo arrastre. In 1889 the ore is said to have assayed $15 per ton. The property was worked in 1893, but is now shut down.

Little Emma.—This claim, situated west of the Blue Dick, shows a pyritous gold ore. Two 28-foot shafts and a 300-foot tunnel prospect the lead. The tunnel is 12 feet wide, and shows ore on contact of limestone and syenite that is said to assay $17 per ton but is not free milling.

Blue Dick.—This claim, on the slopes west of Skunk Creek, shows mineralized contact dipping at 45° into the mountain. The ore is mainly pyrite carrying free gold with copper staining. The ore occurs at under contact of syenite-porphyry and limestone, and shows some brecciation. This property was worked by P. H. Hughes in 1893, the ore being crushed and amalgamated in the arrastre at the Yogo settlement. The ore carried a small amount of silver and gold. A sample of the oxidized "ore" assayed for the Survey laboratory by C. E. Monroe yielded only a trace of gold and 2.2 ounces of silver. One of the sulphide ores gave $1 in gold and less than an ounce of silver to the ton.

Climax.—This claim, like the Christopher Colombo, is on the Wolf Creek side. The ore is a mixture of manganese, pyrite, and galena, and carries considerable lead and some gold.

Bill Cummins.—This prospect yields high-grade lead ores (128 ounces), but in small pockets.

In addition to the prospects mentioned, there are many more in the vicinity of Yogo, some of which were visited, although the workings were generally so shallow that little could be said of the claim.

RUNNING WOLF DISTRICT.

ORE DEPOSITS.

The ore deposits of the Running Wolf Creek district occur in limestone, and, as is so commonly the case with the ore deposits in this rock, they proved irregular in form and limited extent. That they occur on fracture planes either on or near eruptive contacts is apparent from their surface relations, and the ores and waste rock of the mines show that they are replacement deposits. So far as observed they occur on lines of faulting or disturbance too slight to show on the geologic map. The ores consist of galena and its alteration products. At one place, the Walter Scott, the ores are "dry"—i. e., without lead. The common ore is galena mixed with a jaspery gangue. The replacement is shown by a gradual passage from ore into jasper, and this into a silicified limestone showing knots and bunches of silica, and this into unaltered limestone. The jasper is really a mixture of chalcedonic or cryptocrystalline silica, with a little quartz in small bunches and lining cavities. It is usually brown or reddish from iron oxide, and quite plainly occurs as a replacement of limestone usually encasing the galena ore bodies. The caves and water courses seen about such deposits are plainly of recent origin.

The Sir Walter Scott, Mountainside, and Woodhurst are the only mines that have been producers. The region is easily accessible by wagon road, but is so remote from a railroad that low-grade ore bodies can not be worked at a profit. The limited size of the ore bodies and the lack of well-defined veins render the future of the region uncertain. None of the workings were accessible when the region was visited in 1894, and the properties are, it is understood, still idle.

NOTES ON THE MINES.

Woodhurst-Mortson.—This property shows the most extensive development work of any mine of this district. The mine is situated on the south side of Running Wolf Creek, in a recess or niche cut in the steep limestone slopes, some 600 or more feet above the creek. The ore now seen is chiefly galena in a jaspery gangue showing much calcite. The mine buildings are shown on Pl. LXVIII, which also shows the towering walls of massively bedded white limestone that rise behind it. These rocks dip southward, the synclinal folding being due, it is supposed, to the Steamboat uplift. The limestones are intruded by a sheet of syenitic porphyry, whose talus slide is seen alongside of the mine on the east. The material of the dump heap indicates that this porphyry is encountered in the underground workings of the mine. The ore occurs in a contact vein between the porphyry and the limestone. The vein is 2 to 7 feet in width. The workings comprise a shaft said to be 250 feet deep, together with levels aggregating nearly 4,000 feet in length. In 1889 it had yielded 500 tons of carbonate lead ore, carrying 65 per cent lead and 30 ounces of silver per ton, with no zinc.[1] A small smelter was built on the main creek, near the mine. It was run only a short time, and was not a financial success. Over $20,000 worth of work is said to have been done on the property.

Alongside of the Woodhurst-Mortson is a low-grade body of oxidized iron-copper ore, carrying a few ounces of silver. When visited in 1894, this had been prospected by a shaft 50 feet deep.

Sir Walter Scott.—This mine is situated on the flat, elevated summit of a spur of Steamboat Mountain, north of the Woodhurst mine. The vein is said to be 2 to 5 feet wide, and is a contact deposit between limestone and porphyry.[2] The deposit was worked for a short period, about 100 tons being shipped, on which a few thousand dollars was realized. The character of the ore is unlike that of the Woodhurst-Mortson, being a free milling silver ore, carrying 60 to 70 ounces of silver per ton and containing bunches of very rich ore. The geologic structure of the locality has already been noted. The limestones are thinly bedded and belong to the base of the Carboniferous series. The beds dip away from Steamboat Mountain, and are intruded by several sheets of porphyry and cut by trap (minette) dikes trending to Yogo Peak. The mine is accessible by a fairly good wagon road. The property is equipped with comfortable log buildings for boarding house, blacksmith shop, shaft house, etc. The underground workings were not accessible when the property was visited by the writer. Miners familiar with the workings state that the shaft is 300 feet deep, with the usual levels. It is also reported that the ore occurred near the surface, and that the ore body is worked out. The levels tap a large cave, whose bottom is filled by a great pool of water. The material seen on the ore pile shows galena, mixed with copper pyrite and fluorite. Vanadinite collected from this mine by Mr. R. H. Chapman is well crystallized; the specimen has been kindly studied for me by Mr. H. H. Robinson, and the crystals have been drawn under the direction of Prof. S. L. Penfield, of the Sheffield Scientific School, Yale University. Mr. Robinson furnishes the following notes:

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[1] Report State Inspector of Mines, 1889, p. 23.

[2] Ibid., p. 24.

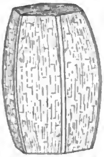


FIG. 70.—Vanadinite crystal, from Sir Walter Scott mine.

The brownish crystals have the form of a hexagonal prism, usually with slight truncations of the edges and a tendency to taper toward the extremities (fig. 70), thus giving the crystals a barrel-like habit which is not uncommon with this species. The surfaces of the prisms are uneven, while the basal planes are rough and usually show a slight six-sided depression. On a few of the very small crystals the faces were sufficiently perfect to admit of measurement with the reflecting goniometer. The habit of these crystals is shown by fig. 71, the forms being the prism m (1010), the pyramid of the first order x(1011), the pyramid of the second order v (1122), and the base c(0001).

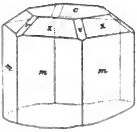


FIG. 71.—Vanadinite crystal, from Sir Walter Scott mine.

Mountainside.—This mine, near the Sir Walter Scott, was not visited. The property was being worked in 1894, and is said to have yielded some $30,000 to $40,000 worth of ore, paying "from the grass roots down."

Yankee Girl.—This claim, discovered and worked in 1894, is a deposit of argentiferous galena and its oxidation products found in limestone. The claim is streaked on the steep slopes south of Running Wolf Creek, about a mile above its forks. The ore body is clearly a replacement. No definite fissure or fault plane was recognized, but the ore occurs in a zone of shattered limestone parallel to the bedding. The central part of the ore body is a nearly pure galena, which grades into a mixture of brown jasper and galena, forming the outer part, and this is incased by an irregular crust of jaspery quartz which grades into the limestone. Several tons were shipped in 1894, the ore being sorted, sacked, hauled on "stone boats" down the steep trail, and thence carried by team to Great Falls. The ore body was 6 feet thick, 200 feet long, and was exposed for a width of 20 feet. The lens dips south at 30°, being nearly conformable with the inclosing limestones. Several other claims in the vicinity—the Ada, Cascade, and Keystone, north of the creek, and the Lookout, one-fourth mile east of the Yankee Girl—show similar occurrences of lead ores in limestone.

Eureka.—This property is situated at the head of the creek, directly under the divide to Lion and Dry Wolf creeks. Small pockets of silver-lead ore were found, but the mine is very generally regarded by the miners of the region as a "wild cat" proposition. The limestones are nearly horizontal, being the center of a synclinal fold or basin. They are cut by a number of dikes of basaltic rock running across the ridge, and the ore deposit is supposed to be connected with these or similar fissures in this zone of fractured limestones. The mine is equipped with a 60-horsepower engine and hoist.

DRY WOLF OR LION CREEK DISTRICT.

The ore deposits thus far prospected in this district occur on the northern side of the Yogo divide, and properly belong to that district.

The only claims examined are on Lion Creek, on the slopes south of Big Park. The alluvial deposits at the mouth of Lion Creek contain gold and have been placered with more or less success at various times.

Lion Creek is a small stream draining the mountain side directly north of the settlement of Yogo and cutting a deep trench in the sedimentary rocks. The strata dip eastward at a gentle angle and are intruded by sheets of porphyry. The ore deposits thus far discovered appear to be contact deposits, and they occur beneath these porphyry sheets.

At the head of the creek small ore bodies are found along the contact between the limestones and the big syenitic stock, and in some cases on dike contacts, but no producing mines have yet been developed. Iron ores also occur at the contacts between limestone and porphyry in Iron Gulch. Large bowlders of this material seen near the Lion Creek settlement consist of very pure limonite carrying 40 to 60 per cent of iron.

The only property as yet developed is the Pierce and Higbee mine, embracing the Dry Wolf, Gold Dust, and Anything claims, which have been surveyed and patented. The property was deserted and the tunnels were not accessible when the place was visited. The ore heap showed galena and chalcopyrite, with their decomposition products. The deposit appears to be on a contact with a sheet of porphyry intruded in the dark-brown Jefferson limestones.

MOUNT TAYLOR MINES.

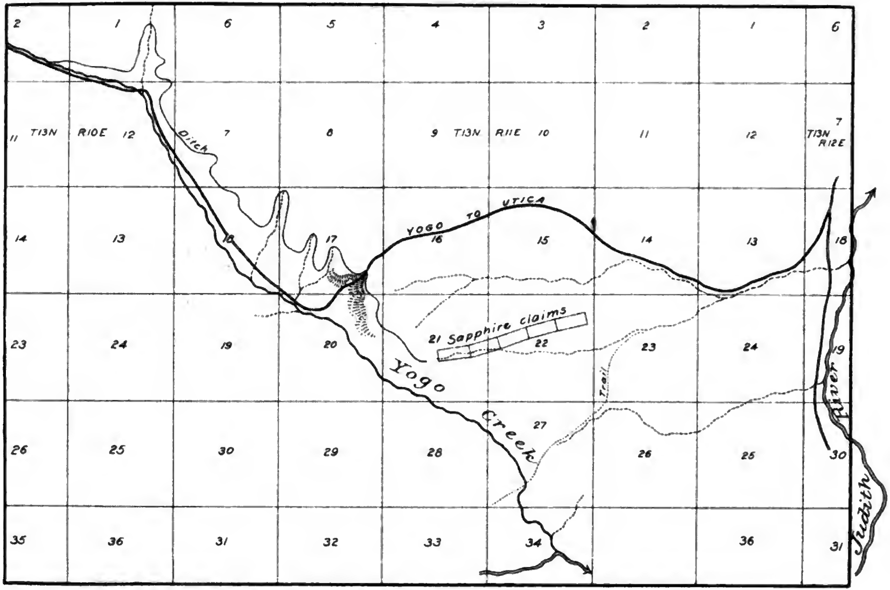
A lead discovered on a high shoulder a short distance below the summit of Mount Taylor has been developed by a shallow shaft, over which a log shaft house has been built. The vein is a fissure in limestone, running east and west, and carries galena and its decomposition products with jasper and oxidized copper ores. A road which has been cut through the forest on the south slopes of the mountain affords easy access to the mine, but sufficient development work has not yet been done to prove the property.

YOGO SAPPHIRE MINES.

The Yogo sapphire mines, which are to-day the most valuable gem mines of the country, are situated in Fergus County, Montana, 13 miles west of the town of Utica. The locality is not accessible by railroad, but can be reached by wagon road from Utica, from which town a stage line runs daily to the railroad at Great Falls. There is also a short cut over the mountains by horseback trail to Neihart, the termination of the Belt Mountain branch of the Great Northern Railway.

These mines are an illustration of the good luck which sometimes occurs in mining. In 1895 a placer-mining company was organized to work the gold-bearing gravels found in pockets upon the limestone bench land lying east of the Yogo fork of the Judith River. A ditch costing $38,000 was built and the waters of Yogo Creek were carried upon the bench land, with a head of 300 or 400 feet. The first season's work demonstrated that the gravels would not pay as gold placers, as a clean-up of but $700 was made as the result of the entire season's work. The sluice boxes, however, contained a large number of blue stones, which were identified in November, 1885, as sapphires.

A cigar box full of the gems collected at this time is said to have been sold to Tiffany & Co. for $3,750. Preparations were immediately made to work the gravels for the sapphires, which seemingly occurred in great abundance in certain parts of the field. It was believed at first that the gems, together with the gold, came from Yogo Gulch, and that the gravels represented an old and high channel of that creek. Their local derivation was discovered by John Ettien, a settler in the neighboring valley of the Judith River, in February, 1896. While prospecting the ground above the placer he noticed a fissure in the limestone, whose soft filling resembled the outcrop of a vein. Two claims were located on it and some of the dirt was taken to the nearest stream and washed. The blue sapphires in the earth were noticed, but it was not until they were shown to the placer workers that their value was known. The importance of this discovery was recognized by Mr. Hoover, one of the owners of the placers, and he and his partners at once located the sapphire lead. It is now known that the gems occur in a dike of trap rock cutting white or gray limestones. This dike has



MAP SHOWING LOCATION OF SAPPHIRE MINES. YOGO DISTRICT now been traced for a distance of 5 miles from the meadows of the Judith River westward to the canyon of Yogo Creek. The entire known extent of the dike has been located as a lode and a large number of claims have already been patented.

The mines are situated in the center of a broad and open basin inclosed on three sides by the Little Belt Mountains, whose wooded slopes show white limestone outcrops that look like banks of snow. To the east high foothill ridges shut in the basin from the open plains country beyond. The Judith River flows through the center of the basin, its three forks uniting at the base of the mountain slopes to the west. The most northerly fork is Yogo Creek, and from it the mines take their name. The claims are located on the bare bench land lying north of the main stream and east of Yogo Creek. The surface has a general easterly slope, having a descent of 800 feet from the brink of Yogo Canyon to the meadow land of the Judith.

Several dry drainage ways traverse the sapphire basin, cutting gulches before they are lost on the alluvial bottom lands. The general aspect of the region is shown in Pl. LV, *B*, made from a photograph taken at the mine settlement, looking westward up the largest of these gulches. In a general view the sapphire locality shows rolling hills whose summits and slopes are formed by the bare and white surface of limestone. The intervening gullies are well grassed, and the gentle slopes show matlike growths of ground cedar. Occasional small groves of stunted pine are seen in a few places, but the general lack of vegetation is in marked contrast to the wooded mountains near by.

The geologic structure of the basin consists of a broad, basin-like fold, opening eastward. It is a synclinal basin, lying between the sharp uplifts on the north and south. While the general structure is thus quite simple, the massive limestones show many minor undulations, and it is largely to them that the present relief of the surface is due, the soft, red earths that overlay the limestone having been carried off from the greater part of the district. As already stated, the gems are found in a dike of igneous rock cutting the limestones. This dike is recognizable upon the surface only by a slight depression, a foot or so deep, emphasized by grass and herbage where it crosses the slopes of bare limestone. In the hollows and gulches the outcrop is recognizable only by the line of gopher and badger holes which mark its extent. No solid outcrops of the dike rock occur, as it alters on weathering to a soft clayey material. This is why its course is marked by gopher heapings, since the adjacent limestone is too hard and undecomposed for these animals to burrow into. These holes, indeed, proved the means of locating the dike when the claims were staked, and many of the finest stones yet obtained were picked up from the heapings made by these animals.

The dike has a general trend S. 56° W. It is from 3 to 6 feet wide, and, so far as shown by the workings, is vertical. It has been traced east and west from the meadow lands of the Judith to the walls of Yogo Canyon, where it apparently ends, as it is not seen in the limestone walls of that canyon, but a few yards west of the crest. It has been found west of the creek bottom, however, at a lower elevation, and, as shown later, it is not seen in the exposure because it did not break quite so far through the limestones at this point. The dike walls are rough, but not especially irregular; they show the bedded limestones slightly indurated by the intrusion. The dike material is somewhat variable in appearance. Near the surface it consists of a coarse breccia of limestone and shale fragments cemented by the igneous rocks. Where the upward termination of the dike is seen, at the westernmost workings, the top part of the dike is a blunt wedge and the material consists chiefly of these rock fragments, as shown in fig. 72. In the main workings, 2 miles farther east and several hundred feet lower in elevation, the excavations show a similar breccia (Pl. LXVII, *B*) at the surface, but the size and number of the fragments decrease with the depth. This is believed to be the fragmental material from the fissure walls, which has been floated upward as the molten rock rose in the fissure, like chips on the surface of a stream of water.

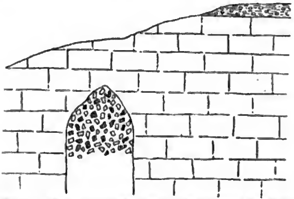


FIG. 72.—Section of upper limit of sapphire-bearing dike, wall of Yogo Canyon.

The workings were in 1897 entirely in altered rock, the shaft being at that time only 60 feet deep. (Pl. LXVII, *A*.) At this depth it had passed out of the zone of surface alteration, and the ocherous, yellow clay was replaced by a blue clay which reminds one very much of the description given of the Kimberley diamond matrix. Throughout this clay there are bowlders of the unaltered rock, with kernels of solid material, which have been broken open and furnish specimens for petrographic description. In the shaft the entire width is 11.4 feet from wall to wall. Of this, 3.7 feet on the south wall was of solid minette, checked with calcite seams, but otherwise comparatively fresh and unaltered. The clay does not always bear the same relation to the walls, but jumps across from one side to the other. In the workings it is at once seen that the upper part of the dike is largely a breccia—that is, it consists of a mixture of dike material and the limestone fragments. It appears to be somewhat near the apex of the dike. The questions naturally arise, how far the relative abundance of these limestone fragments have influenced the formation of the sapphires, and whether the sapphires will continue in depth or not. For this reason a very careful examination was made of the shaft and of the blue clay which was seen there.

A.

B.

SAPPHIRE MINES OF YOGO DISTRICT.

A. Shaft in 1897; Ricard Peak in distance.
B. Face of dike in open cuttings 1897.

The writer was unable to find any sapphires in the blue clay itself, but was assured that when washed the blue clay yielded a fair proportion of the gems. There seems reason to believe that this blue clay will require a special treatment, inasmuch as it is very tenacious and does not yield readily to ordinary washing. In all probability it will have to be handled as the blue clay of Kimberley is handled for the extraction of diamonds. The gems in this blue clay are said to be much finer than those in the more altered material. This one can readily believe, because the sapphires in the altered rock are so checked and fissured that even when found in place they split up into chips of no value for cutting. In the blue clay the gems would not have been subjected to the strains and processes incident to the decomposition and expansion of the rock, and therefore should yield a very much larger proportion of cuttable stones.

At present the greatest amount of material is derived from an open cut, some 400 or 500 feet in length, upon the highest part of the claims. Three windlasses are employed, and men are at work with pick and shovel, digging the soft, yellow earth and throwing it into shallow tubs, which are hauled to the surface, where the earth is thrown into ordinary dump carts. It is then hauled about a quarter of a mile to the ditch and shoveled directly into sluice boxes. In the sluices the harder bowlders and the balls of blue clay are carried through the riffles and accumulate upon the tailing dumps. Probably not over 33 per cent of the gems are recovered in this first washing. By exposure to the atmosphere and by the frequent freezing and thawing which takes place in this frosty climate the blue clay slacks and disintegrates, so that the material can be washed over, with a further extraction of gems.

At the time of the writer's visit some 20 loads, each approximating a square yard of earth, gave between 1,200 and 1,500 carats of cuttable stones. The value of the stones in London market is $6 a carat for the first quality, $1.25 a carat for the second quality, and 25 cents a carat for the gleanings. The larger stones found weigh, when cut, 4 to 5 carats, and are then valued at $75 a carat.

In sluicing the earth the process followed is similar to that of washing gold-bearing gravels, but no mercury is used. The gems drop between the riffles and are obtained at the close of each day's work by turning off the water and lifting the racks. This material from the riffle is then sifted and panned by hand, to get rid of valueless materials. The result is a concentration of the sapphires, together with grains of pyrite, from which the gems must be picked by hand. This pyrite is the only other mineral found with the gems. It has been assayed for the writer and found to contain a little silver, copper, and nickel, but no gold. The pyrite is in moss-like aggregates and not in well-shaped crystals. The clay contained a few hexagonal crystals, which had the form of corundum, but consisted of some decomposition product and showed no trace of the original mineral. The shaft has been sunk to a depth of 300 feet, and considerable masses of corundum are said to have been found at that depth.

As already stated, in the upper part of the dike the rock is largely altered to a yellowish clay in which only the fragments of sedimentary rock are recognizable. At depths of 20 to 40 feet below the surface bowlders of the igneous rock are found. They are clearly nucleal masses not yet decomposed by surface waters. In some places considerable masses of the solid dike rock are also found, and every gradation may be observed, from the tough and resistant dark-gray dike rock to the soft yellow clay into which it finally decomposes.

The freshest material has been carefully studied and proves to be a lamprophyre rock. In the hand specimen it is dark gray, has an uneven, rough fracture, and is evidently a tough and heavy trap rock. The rock shows numerous angular inclusions of white or pale-green color, which vary in size from those of microscopic dimensions to masses a foot or more across. The large inclusions consist chiefly either of quartz or of crystalline calcite surrounded by a rim of pale-green pyroxene of small but variable width. Some of the smaller inclusions consist entirely of this green pyroxene, and it is also recognizable in the calcite center of the larger pieces.

The dike rock itself is very dense, dark colored, and glistens with the light reflected by innumerable flakes of biotite, of which the rock is seemingly composed. Pyroxene is recognizable to the eye. A few scattered tablets of brown mica—the largest seen a quarter of an inch across—are the only phenocrysts. The rock has been described by Professor Pirsson,[1] and the results of his microscopic study are given in the following paper. Under the microscope the rock is seen to consist of biotite and pyroxene in closely crowded masses. There is no feldspar present, but a small amount of interstitial kaolin-like material occurs. The rock is most like a mica-pyroxene-analcite-basalt.

The sapphires occur embedded in this rock in well-formed crystals and in rounded masses $\frac{1}{20}$ inch to $\frac{3}{4}$ inch across. They were found in the freshest unaltered rock obtained, as well as in the altered decomposed material. They show no connection with the included fragments and are always distinct and sharply defined. Their crystalline form is fully discussed by Pratt,[2] a summary of his work being given in Professor Pirsson's report.

The occurrence of the sapphires shows quite conclusively that they were formed in the dike rock itself. Their origin is believed to be the result of the action of the molten igneous rock upon fragments of clay shale or impure limestone, taken up by the former in its ascent, as suggested by Pirsson. This implies the complete assimilation and digestion of such material in the igneous rock. It is apparent from a study of the sapphires themselves that they crystallized out of the rock, but it is also evident that partial resorption took place before final consolidation, since many of the sapphires show deeply corroded surfaces; others are rounded masses whose crystalline outline is

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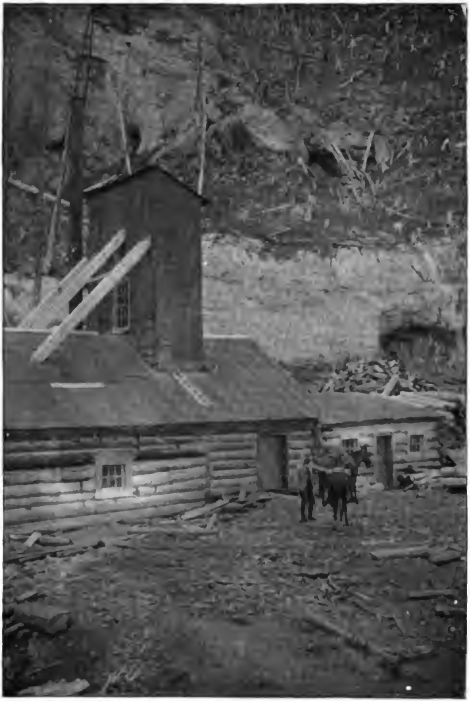
[1] Am. Jour. Sci., 4th series, Vol. IV, 1897, p. 421.

[2] Ibid., p. 424.



WOODHURST-MORTSON MINE, RUNNING WOLF CREEK

Limestone cliffs seen back of buildings rise abruptly to summit of ridge nearly effaced, while many of them are surrounded by a blackish crust. If the molten rock could dissolve the sapphires at this stage, it is certain it could dissolve clay shale as well. The dike undoubtedly extends a considerable distance in depth. The limestones are 1,000 feet thick in this vicinity, and rest upon nearly a thousand feet of Cambrian shale. The Belt formation is believed to be absent, but the Cambrian beds contain almost every possible variety of calcareous, siliceous, and argillaceous rocks. It is remarkable, however, that, though sapphires are found throughout the entire extent of this dike, they do not occur in the parallel dike of nearly similar rock that cuts the limestone 600 feet north of the sapphire claims, nor have gems been found in the augite minettes that occur as dikes and sheets in the shales of the Quadrant formation southeast of the mines, along the border of the Judith River bottom land.

A parallel dike about 600 feet north of the sapphire dike weathers to a sandy, micaceous material that probably represents the outcrop of a minette dike cutting through the limestone. A few kernels of partly altered rock were found where prospecting had been done on the dike. The rock and its débris show no sapphires, although many cart loads of the dirt have been washed from different points along the outcrop. It seems probable, however, that this dike is the source of the gold found in the placers, as the colors can be traced up the gulches to the outcrop of the dike and never occur beyond it.

IRON ORES OF THE LITTLE BELT MOUNTAINS.

Deposits of limonite and hematite are found at a number of localities in the Little Belt Mountains, and the small amount of development work which has been done thus far shows that they are of sufficient purity and extent to be workable and will some day be utilized in Montana furnaces. The material is very dense and hard, resisting erosion better than any of the rocks of the region, so that the float from such deposits is often very noticeable in the drift and gravels of the region. The occurrence of the ores is noted by Eldridge, who says:[1]

> In the Judith Basin, at the southwestern edge of the map, there occurs, in addition to the stratified rocks already mentioned, a narrow belt of granite, width undetermined, accompanied by a band of magnetic iron ore, the relations of which to the stratified rocks were, for various good reasons, left undetermined. The ore is steel gray, strongly magnetic, unless, as in few instances, exposure to atmospheric influences has altered it to limonite. It outcrops in heavy masses from one-half ton to 20 tons weight, the outcrop varying in width from 2 feet to what would seem from the float to be at least 15 feet, though perhaps this may be too great a width. The question of width could only be solved by systematic prospecting. The trend of the ore body is, as nearly as could be determined, about north 70° west. In the vicinity of the head of Wolf Creek it was traced by float for 2 miles, but with an intervening space of a mile where it could not be found, owing perhaps to a cover of soil and débris. At one point on its course it was traced continuously for 3,000 feet. The guide who was with the party, and in whom every confidence as to truth in this matter can be

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[1] Tenth Census of the United States, Vol. XV, p. 751.

placed, states that he has traced it from 3 to 6 miles farther to the westward, or midway between the head of Wolf Creek and the Barker mining district, seen on the general maps of the Survey. Magnetic iron ore is also reported on good authority in the Barker mining district itself.

The only other points at which iron ore was observed on the border of the Judith Basin were in the Judith Mountains, north of the Maiden mining camp, where is also found a limited amount of magnetic iron ore, together with a mass of bog ore (limonite), resulting from the breaking down of the magnetite, which occurs higher up on the mountains.

The locality mentioned by Eldridge is undoubtedly Woodhurst Mountain, and the contact referred to is that of the Woodhurst stock.

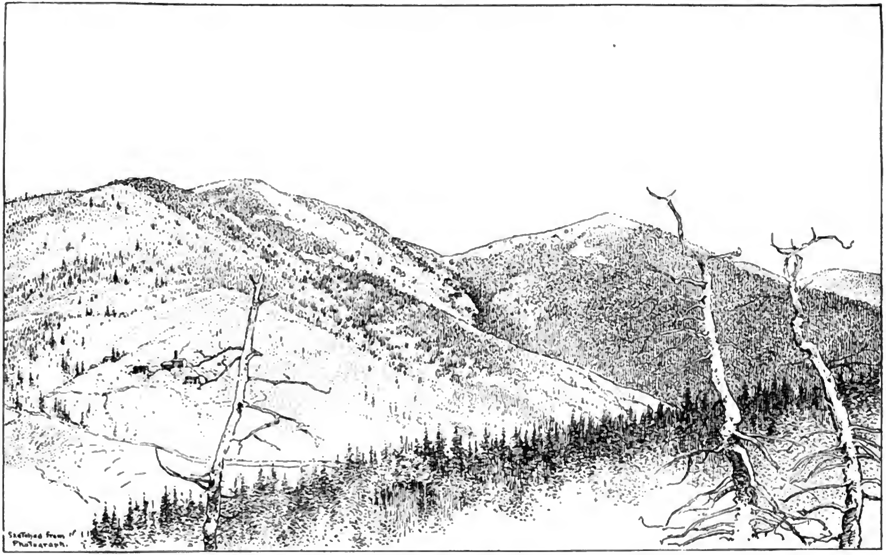
From the general study made of the region it is evident that no general lead extends across the mountains, but that lenticular bodies of ore occur at the contacts of many of the masses of igneous rock. They were observed on Woodhurst Mountain, on Iron Creek, on a branch of Lion Gulch, at a point north of Yogo, on the mountain top above that place, and on Thunder Mountain. Iron-ore float was observed at other localities, and there seems little reason to doubt that it is of common occurrence about most of the larger igneous intrusions.

Woodhurst iron mine.—The Woodhurst Mountain deposits have, so far as known, been prospected at only one place. These workings are on the southeastern flank of the mountain, at the head of a small drainage tributary to Galena Fork of Running Wolf Creek. The locality, though remote from a railroad, could be made readily accessible by wagon road. The deposit has been opened by surface cuts, exposing a continuous mass of hematite in a trench 40 feet long, cut at right angles to the contact and hence across the lens. The deposit lies at the base of a projecting tongue or offshoot of the porphyry body of Woodhurst Mountain, and is clearly a contact deposit. The porphyry is somewhat altered and rotted, but the Carboniferous limestones show only slight alteration. The claims are 600 feet above the forks of Running Wolf Creek. An analysis of the ore, made by Dr. W. F. Hillebrand in the laboratory of the United States Geological Survey, gave Fe_2O_3, 83.7 per cent; FeO, 6.4 per cent; Mn, none; TiO_2, none; P_2O_5, trace. The remainder is mostly silica. The ore is strongly magnetic, and is evidently a mixture of magnetite, hematite, and the hydrated oxides of iron.

Iron Creek or Lion Gulch.—These deposits were not examined, but the character and amount of ore seen in the gulch warrants an examination of the locality.

Yogo deposits.—A lens of quite pure hematite 2½ feet thick was observed on the mountain ridge east of the head of Skunk Creek, near Yogo. The deposit occurs at the contact between limestones and a dark-colored, coarsely granular rock (shonkinite).

Thunder Mountain iron mines.—On the north side of Thunder Mountain, at the head of Iron Creek and at an altitude of 6,000 feet, the contact between the porphyry and sedimentary rocks is marked by contact



Sketched from Photograph.

MOUNTAIN RIM NORTHEAST OF BARKER BASIN FROM SLOPES OF BARKER MOUNTAIN. BARKER DISTRICT.

Road to Kibbey and Otter Creek on left, with Paragon mine above. Clendennin Mountain on left; Mixes Peak (locally "Baldy") on right. Tiger and Moulton mines in gulch between.

lenses of iron ore. The sedimentary rocks are locally baked and metamorphosed, the soft micaceous Cambrian shales being changed to hard, flinty hornstones. The iron ore is, in part at least, a replacement of these rocks and occurs between them and the granite-porphyry. The ore is in lenses varying from a few feet to 20 feet in thickness, whose lateral extent is not exposed by outcrops or by the artificial openings thus far made. The ore is at present exposed in an open cut, and the quantity appears to warrant mining if there should arise a demand for such ores, since the ore could be easily transported, by some gravity system, to the railroad. Analyses of the ore, made for the owners and published in the Neihart Herald, show Fe_2O_3, 76.90 per cent; FeO, 0.07 per cent; Mn, 0.03 per cent; SiO_2, 8.80 per cent; Al_2O_3, 0.74 per cent; S, 0.03 per cent; H_2O, 13.36 per cent.

From the analyses it would appear that the ore is a fairly pure limonite mixed with a little quartz; but the ore is magnetic, and hence must be a mixture of magnetite with limonite derived from it. Openings along the contact on the southern side of the mountain also showed iron ores, but their existence was not determined.

PETROGRAPHY OF THE IGNEOUS ROCKS OF THE LITTLE BELT MOUNTAINS, MONTANA.

By L. V. PIRSSON.

CHAPTER I.

INTRODUCTION.

PREFATORY REMARKS.

The present work embraces a somewhat detailed description of the petrography of the region of the Little Belt Mountains. Although a considerable portion of the rocks are classified under simple and well-known types, or present but slight divergences from them, it has been deemed best to give a rather full account of them and accompany it with analyses, since the area is a mining region which is growing in importance, and a detailed description of the igneous rocks, with which most of the mining industries stand in close relationship, will be of local service.

It is also thought that, since even these well-known types of rocks, such as granite-porphyry, syenite-porphyry, etc., are not devoid of certain regional characteristics and individual peculiarities, their description will be of interest to the petrographer.

The greater part of the occurrences here described have been visited and collected from by the writer while in company with Mr. W. H. Weed, through whose kindness and cooperation he was enabled to enter the field during the progress of the areal mapping of the region, by Mr. Weed, for the United States Geological Survey.

In this portion of the work only such details of descriptive geology will be given as will enable the reader to locate the types described and refer them to their proper places in the descriptive geology by Mr. Weed in the foregoing pages.

CLASSIFICATION.

In regard to this vexed subject, it has seemed best to divide the types to be considered primarily into four groups: *a*, the *granular nonporphyritic rocks*, which are here of plutonic origin and which mainly form intruded stocks, but in a few cases are found as dikes; *b*, the *acid feldspathic porphyries*, which are usually light-colored rocks composing the laccoliths of the region and a considerable portion of the dikes and sheets, and with which are included several dense types which lack phenocrysts and may be considered as imperfectly developed porphyries; *c*, the *lamprophyres*, or dark-colored basic rocks, composed mainly of ferromagnesian minerals, and found only in dikes and sheets, usually of rather small dimensions; and *d*, *effusive rocks*, or lava flows, which in this area are restricted to two occurrences of basalt.

In the nomenclature no regard has been paid to the fast-dying and nearly obsolete qualification of geologic age; thus, *rhyolite* has been used irrespective of the consideration whether the rock so called is of Tertiary or of pre-Cambrian age. The term *porphyry* has been used simply as one of structure, not as the name of a kind of rock, and hence is used as a suffix to any of the names of the rock families, as, for instance, *diorite-porphyry* in place of diorite-porphyrite. This is merely restoring the word to its earlier, more logical, and correct usage, and is in full accord with the best and prevalent American practice.[1]

In the first group of granular rocks are found representatives of the *syenites*, *monzonites*, *diorites*, and *shonkinites;* in the second group are various representatives of the *granite*, *syenite*, and *diorite* families in the form of porphyries and densely textured rocks; in the third group, that of the lamprophyres, we find *minettes*, *vogesites*, and *analcite-basalts* of various types, with transitional forms as well; while in the last group there is only common *feldspar-basalt*.

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[1] See J. D. Dana's Manual of Mineralogy and Petrography, 1887, p. 441.

CHAPTER II.

THE GRANULAR ROCKS.

From the standpoint of general geology the granular rocks are by no means so important in this district as are the porphyritic. The most notable occurrence is that of the Pinto diorite of Neihart. In addition, the list of occurrences includes the syenites of Barker and Belt Creek, the analcite-syenite of Otter Creek, and the stock of Yogo Peak, which is differentiated into various rock varieties, such as syenite, monzonite, and shonkinite.

BARKER SYENITE.

The syenite which forms the intruded mass north of Barker has several mines located upon its contact, like the Wright and Edwards, Barker, etc., from the dump heaps of which most excellent fresh material can be obtained. The rock is of a gray color, of moderately fine grain, with occasional large feldspars, half an inch or so long, which are phenocrystic in character. It is thickly dotted with small anhedrons of a black ferromagnesian mineral, and is locally termed "granite."

Under the microscope the minerals of a typical syenite are disclosed, viz, iron ore, hornblende, pyroxene, apatite, alkali feldspars, a little oligoclase, and a little quartz. The iron ore and apatite are of the character usual in rocks of this class. The hornblende is mostly of a stringy, fibrous character, and plainly paramorphic after the pyroxene with which it is connected; but in some specimens, such as those from the Wright and Edwards mine, the hornblende is idiomorphic, compact, and of the usual olive-green pleochroic character seen in many syenites and diorites, and must here be regarded as primary. The pyroxene, which has been mostly changed to hornblende, is a pale-greenish diopside of a wide extinction angle. The feldspars are of greater interest; they consist mainly of alkali kinds which have no good outlines but always have a tendency to a broad tabular habit. They are soda-bearing orthoclases, and in them the section perpendicular to $\mathfrak{a}$ exhibits 2E varying from 40° to 50°, with extinction parallel to the very good cleavage lines which show the trace of 001 on the section. In sections perpendicular to $\mathfrak{c}$—that is, nearly parallel to 010—the extinction is 9° plus, as measured from the cleavage of 001, the direction of the vertical axis and the orientation of the angle β being shown by inclusions and a parting parallel to m (110). These soda orthoclases contain interlaminated perthite bands of albite; they also occasionally contain small cores of oligoclase; the included plagioclase may, indeed, be an acid andesine, as shown by Becke's method. Albite may be present in independent crystals and also oligoclase, as shown in some cases by the simultaneous illumination of sections in the zone perpendicular to 010 of excellent Carlsbad twins with their albite lamellæ, while other crystals are those of oligoclase. The amount of plagioclase present is always small in comparison with the alkali feldspar. Of the quartz, a small quantity is seen, mostly interstitial, the last product of crystallization, though sometimes in more or less small rounded anhedrons inclosed in the outer boundary of the feldspar.

The structure of the rock is purely granitoid, though the occasional larger orthoclases give it sometimes a slight tendency to a porphyritic structure. The chemical composition is shown in the following table of analyses:

Analyses of syenites.

Constituent.	I.	II.	III.	IV.	V.	VI.
SiO_2	64.64	65.43	65.54	68.34	59.78	1.077
Al_2O_3	16.27	16.11	17.83	15.32	16.86	.158
Fe_2O_3	2.42	1.15	.74	1.90	3.08	.015
FeO	1.58	2.85	1.15	.84	3.72	.022
MgO	1.27	.40	.98	.54	.69	.031
CaO	2.65	1.49	1.92	.92	2.96	.047
Na_2O	4.39	5.00	5.55	5.45	5.39	.070
K_2O	4.98	5.97	5.58	5.62	5.01	.053
H_2O at 110°	.09	.19	.54	.15	1.58	....
H_2O above 110°	.27	.39		.30		
TiO_2	.51	.50	.11	.21	?	....
P_2O_5	.37	.13	Trace.	.13	....	....
ZrO_2	....	.11	....	....	....	....
SO_3	Trace.	....	....	Trace.	....	....
FeS_2	....	.07	....	....	....	....
CO_2	.37	Trace.	....	....	.75	....
Fl	....	.08	....	....	....	....
Cl	.05	.05	....	.04	....	....
MnO	Trace.	.25	Trace.	.07	.14	....
BaO	.18	.03	Undet.	.08	?	....
SrO	.08	....	Undet.	.04	?	....
Li_2O	....	....	Trace.	None.	....	....
Total	100.12	100.18	99.92	99.95	99.96	....
Less oxygen (O)	.02	.04	....	....	....	....
Remainder	100.10	100.14	....	....	....	....

I. Syenite (No. 633), Wright and Edwards mine, Barker, Montana. W. F. Hillebrand, analyst.

II. Syenite, Mount Ascutney, Vermont. Jaggar and Daly. See Bull. U. S. Geol. Survey No. 148, by Clarke and Hillebrand, p. 68. W. F. Hillebrand, analyst.

III. Syenite, Highwood Peak, Highwood Mountains, Montana. L. V. Pirsson and W. F. Mitchell, analysts.

IV. Syenite, Head of Beaver Creek, Bearpaw Mountains, Montana. Weed and Pirsson: Am. Jour. Sci., 4th series, Vol. 1, 1896, p. 354. H. N. Stokes, analyst.

V. Syenite, Blue Mountains, Colorado. W. Cross: Proc. Colorado Sci. Soc., 1887, p. 240. L. G. Eakins, analyst.

VI. Molecular ratios of No. I.

This analysis is quite typical for a syenite, in respect to the high silica, alumina, alkalies and low lime, magnesia, and iron. The silica is toward the upper limit of the syenite group, verging on the granites, and this explains the amount of quartz which is present. Since the quartz, however, is small and entirely microscopic, it appears best to classify the rock as a syenite rather than a granite. For sake of comparison, the analyses of some other quartzose syenites, mostly of western occurrences, are given. The silicia in No. IV is very high, running into the granite group, but this is because the rock is almost pure feldspar; the actual amount of quartz present is very small.

From the molecular ratios given in No. VI we may calculate the percentage of minerals present. In the specimen analyzed the only dark minerals present are iron ore and hornblende. We may assume that all of the alumina is in the feldspar, all the ferric oxide in magnetite; then the excess of alumina over alkalies demands an equivalent of lime to form anorthite. Thus the excess of lime over the anorthite, the excess of ferrous oxide over the magnetite, and the magnesia are the elements forming the hornblende, and they are present in the ratio

$$Ca : MgO, FeO :: 0.012 : 0.038 = 1 : 3.1,$$

while the theory for hornblende, $Ca(MgFe)_3(SiO_3)_4$, demands 1 : 3.

This result is remarkably close and is another proof of the marvelous accuracy of Hillebrand's analyses. These results show that the rock has the following mineral composition, in parts by weight:

	Per cent.
Magnetite	3.6
Hornblende	5.5
Anorthite	10.0
Albite	37.4
Orthoclase	30.1
Quartz	13.4
Total	100.0

If all the albite and anorthite were combined to form plagioclase, the resulting feldspar would be an oligoclase, $Ab_{140}\ An_{35}$, or exactly $Ab_4\ An_1$. The microscope shows, however, that the average plagioclase present is not so rich in soda, but approximates to $Ab_2\ An_1$, and this permits of the presence of the albite molecule in the soda orthoclase and in the microperthite intergrowths.[1]

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[1] The albite molecules are thus about equally divided, and the ratio of plagioclase to alkali feldspar is about 7 : 12, which shows a syenite verging toward the monzonite group of Brögger.

From the foregoing results we can calculate approximately the chemical composition of the hornblende present, and find it to be as follows:

	Per cent.
SiO_2	55.1
FeO	9.3
MgO	23.3
CaO	12.3
Total	100.0

This is, in fact, the ordinary composition of a common hornblende, though perhaps a little richer in iron than usual.

In making these calculations the minute amount of lime necessary to turn phosphoric acid into apatite, of ferrous iron belonging in ilmenite, and of the barium and strontium in the feldspar, have not been taken into account; possibly if they had been the results would be a trifle more accurate.

AUGITE-SYENITE OF BELT CREEK.

This occurs as a thick intrusive sheet, reaching 100 feet in thickness in places in the Cambrian beds on Belt Creek, and extending from 3 to 6 miles above its junction with the Dry Fork. It has been previously mentioned by Lindgren[1] in his two publications on this region, and a brief description of it given. The collection of new and more varied material has added much of interest to the original study, and the whole is herewith given in full.

The rock is of a medium fine grain, and in color of a grayish tone with light-pink spots. The general gray tone is due to the feldspar granules being thickly sprinkled with exceedingly minute dots of a ferromagnesian mineral, to be seen only with a powerful lens. In these grayish feldspars are scattered many tablets of biotite, while occasional quite large formless inclusions or phenocrysts of a pink alkali feldspar are seen. A few included quartz grains with greenish mantle were noted. The rock also contains some inclusions, as large as one's finger, of another rock, which appears to be a minette, with micaceous groundmass and phenocrysts of biotite. The rock surface exhibits many small miarolitic cavities studded with projecting feldspars of poorly developed crystal form. The microscope discloses in the section the following minerals: Iron ore, titanite, apatite, diopside, biotite, alkali feldspar, and quartz.

The iron ore and apatite are of the usual character; the titanite is not very common and is in small, well-formed crystals. The pyroxene, which is of a clear, very pale-yellow green, has an extinction angle of about 45°, and is of diopside character. It occurs rather sparingly in good-sized crystals 1 or 2 mm. across, but also in great quantities of very small, well-formed, slender prisms which are thickly scattered through the feldspars, the latter inclosing them in a poikilitic manner.

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[1] Tenth Census of the United States, Vol. XV, p. 723; Proc. California Acad. Nat. Sci., 2d series, Vol. III, p. 45.

The biotite also occurs in the same manner, and is in crystals of two sizes, the smaller embedded in the feldspar, but it is much less in amount than the diopside. The feldspar, which is the chief constituent, has a short, thick, tabular habit, giving square or rectangular cross sections; in a section parallel to *b* (010) and perpendicular to *c* the extinction is 10° 30′ from the trace of 001, and hence the feldspar is a soda orthoclase; and this is also shown by its marbled, patchy, moiré appearance between crossed nicols with high powers. Moreover, there being but one variety present, it would naturally be rich in soda. The average size of feldspar grain is between 1 and 2 mm. In some of the angular interspaces between the feldspars is a little quartz, or quartz and feldspar in micrographic intergrowths.

The striking feature of this rock is the small augite prisms embedded in the feldspar. The large occasional pink feldspars are quite free from them, and must therefore be an earlier product. The rock is thus an augite-mica-syenite verging on the syenite-porphyries.

A specimen collected at another outcrop of the sheet shows a slightly different character. There is more mica present, titanite is wanting, and the feldspars are smaller and tend more to a lath-like form. This variety agrees more closely with the description of Lindgren, and is undoubtedly the variety examined by him. He refers it to the mica-syenites or minettes, stating that it has a tendency to the augite-syenites. In his second article it is referred to the augite-syenites, where it clearly belongs.

ANALCITE- (NEPHELITE-) SYENITE.

Rocks of the nephelite-syenite group, or those composed chiefly of alkali feldspars in combination with a feldspathoid mineral of which nephelite may be taken as the type, are rare in the Little Belt Mountains, only one occurrence being known, which may be referred to under this heading.

The rock forms an intrusive mass on the west side of upper Otter Creek, about 6 miles north of Barker. It is first mentioned and described by Lindgren,[1] who gives some brief petrographic data concerning it. Some additional details are given in a later publication.[2] The following account supplements that given by Lindgren:

It is rather fine grained and of a light-gray color, due to a mingling of the white feldspathic material with innumerable small, slender foils of biotite, which lie pointed in every direction and produce a markedly speckled appearance. In the maximum these foils of biotite attain the length of half an inch, but their thickness is not over one-twentieth of this, and commonly they appear not over an eighth to a quarter of an inch long. They are not the edges of thin tables of biotite that are seen on end, but actually have this curious rod-like development, and appear at first sight much like slender hornblende prisms. Among these glittering biotites are roundish flecks of dull greenish black, which are due to small, stout prisms of pyroxene. The average size of grain and texture is similar to that of an ordinary granitic aplite. To these details the lens adds little beyond showing that the feldspars have a pronounced thin tabular habit.

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[1] Tenth Census of the United States, Vol. XV, p. 723.

[2] Proc. California Acad. Nat. Sci., 2d series, Vol. III p. 45.

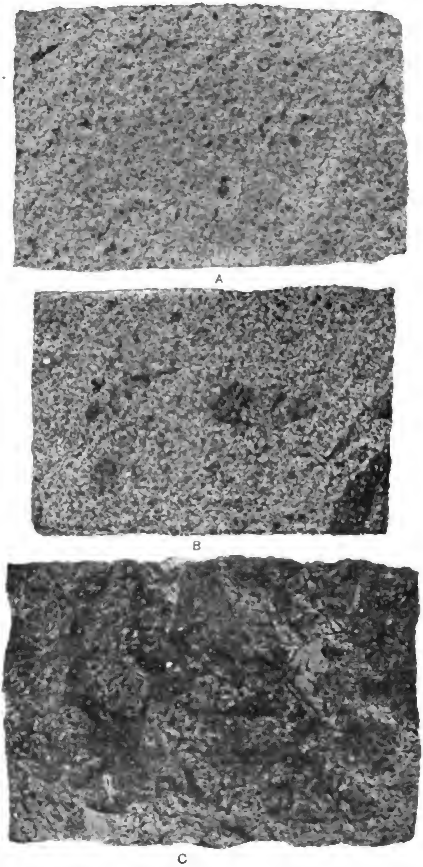
In thin section the microscope discloses the following minerals: Iron ore, apatite, pyroxene, biotite, muscovite, alkali feldspars, nephelite (?), and analcite, while a little calcite and serpentine are clearly secondary products.

Iron ore occasionally occurs in rather large scattered anhedrons. The apatite in its usual prisms is closely associated with the iron ore and pyroxene. The pyroxene is moderately abundant in thick, short prismoids. It has a clear, pale gray-green color, and exhibits in places a faintly perceptible pleochroism in tones of the same color. Its extinction angle on 010 is about 45°. It is clearly a member of the diopside family. In places along the cleavages and cracks it is altering into a yellowish, fibrous, serpentine-like product.

The biotite has a strong pleochroism varying between a dark red-brown color and a very pale yellow, almost colorless. Its most marked feature is the development into long, slender foils. It is strikingly idiomorphic and free from inclusions.

The feldspars appear to be wholly made up of alkali varieties. In some of them interior cores remain which are clear, homogeneous, and unaltered, and which seem to be of soda orthoclase. Generally, however, the feldspars are more or less flecked and muddy. They contain occasional strips of muscovite, and more especially small bays and areas of a colorless isotropic mineral of low relief, which, as will be presently shown, is undoubtedly analcite. Generally between crossed nicols the feldspars show the mottled look characteristic of soda orthoclases which are being altered. Small areas and occasional laths show the albite twinning, and are due to albite. The feldspars have a pronounced lath shape, giving the section a broadly trachytoid appearance.

In the interstices between the feldspars is a colorless isotropic mineral of very low relief, which is analcite. There is considerable of it present. That it is analcite is shown by the fact that if the powdered rock is boiled with extremely dilute acid the resulting solution when filtered and evaporated yields gelatinous silica abundantly. This shows the mineral is not leucite. The filtrate when tested with silver nitrate yields but the faintest perceptible trace of chlorine and none of sulphates, which excludes sodalite and nosean. On application of heat in a closed tube the rock powder yields water readily and abundantly far below redness. These tests show a considerable amount of analcite present in the rock. In his earlier publication Lindgren was inclined to believe that this analcite was glass, and believing the rock to be of younger age he placed it among the trachytes, but in his later work he recognized that it might be a mineral of isometric character, perhaps sodalite, and classified the rock as an augite-syenite.



IGNEOUS ROCKS OF YOGO PEAK.

A, Syenite. B, Monzonite. C, Shonkinite.

A little calcite and muscovite are present as secondary alteration products. It seems probable that the analcite is also wholly, or at least in great part, secondary, probably after nephelite or sodalite in the angular interspaces, and partly after the albite molecule in the feldspars. The rock is thus somewhat changed along the line of zeolitic alteration.

Whether we assume the analcite filling the angular interspaces to be secondary or original, the rock in any case belongs in the nephelite-syenite group. If we assume that it is secondary after nephelite, as seems most probable, the rock is to be classed as a miascite. The presence of some nephelite in the rock could not be directly proved, but it is suspected from the section.

THE ROCKS OF YOGO PEAK.

The rock mass of Yogo Peak and the different rock varieties into which it is differentiated have already been described by Mr. Weed and the writer.[1] In that article only brief petrographic details were given, sufficient to make clear the discussion of the analyses and the facts bearing on theoretic petrography, which comprised its essential features. It is here proposed to treat these types in more detail, especially those points which are of interest to petrographers. The discussion of the facts from a standpoint of theoretic petrography is deferred until the latter part of this work. For details of descriptive geology the reader is referred to the description by Mr. Weed in the first portion of this work.

SYENITE OF YOGO PEAK.

That portion of the Yogo Peak stock which may be most properly classified as a syenite comprises the eastern shoulder of the elevated mass. The rock has a platy parting which causes it to split readily, making the joint blocks a foot or so long. They are very hard and tough, and specimens are broken off with difficulty. The rock is unaltered, fresh, and very suitable for study and analysis.

On a freshly fractured surface the rock appears evenly granular, of moderately fine grain, and is compact in character and with few miarolitic cavities. The color is a medium gray, with a pinkish tone. An illustration of it is shown in Pl. LXX, *A*. Examined with the lens, it is seen to be chiefly composed of light-colored feldspar, dotted with small, dark, formless spots of green pyroxene or hornblende.

The microscope shows the following minerals to be present: Apatite, titanite, iron ore, pyroxene, hornblende, biotite, orthoclase, oligoclase, and quartz. The apatite and titanite are of the usual characters common to such rocks. The iron ore is not abundant and occurs in small grains of about 1 mm. in diameter. The pyroxene is a very pale green diopside, and is much cracked and broken up. Frequently it appears like a bundle of rods. It is rarely alone, generally occurring in common with a brownish-green hornblende. The two minerals are very frequently found together in stout, ill-shaped crystals from 1 to 2 mm. long, the pyroxene forming a core surrounded by the hornblende. In such cases the amount of pyroxene is inversely proportional to that of the hornblende. The appearance and association of these two minerals indicate that the hornblende is paramorphic after the pyroxene. The latter rarely occurs alone, while the hornblende frequently does. Biotite is rare, and occurs only as occasional brown pleochroic shreds.

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[1] Am. Jour. Sci., 3d series, Vol. L, 1895, p. 467.

Orthoclase is the predominant feldspar, occurring in irregular masses. A smaller quantity of plagioclase is also present, the optical characters of which prove it to be oligoclase. It is more idiomorphic than the orthoclase, frequently or even commonly occurring in rather rectangular elongated laths. and is often surrounded by a mantle of orthoclase. A small amount of interstitial quartz completes the list of minerals.

In structure the rock is hypidiomorphic, but only partly so, as the pyroxene and hornblende are themselves rather ill formed and irregular, and the tendency is toward an allotriomorphic structure. The average size of grain is about 1 mm.

The analysis given in No. I of the following table shows the chemical composition, which is that of a syenite with rather high lime, iron, and magnesia for a rock of that group. The mineral and chemical character show it to have a somewhat dioritic tendency, and in fact it is closely related to the monzonite group, in which the feldspars are equal; that is, approximately the plagioclase equals the orthoclase. It is very closely related to certain of the syenites which have been called akerites, as the analysis of one of them tends to show. Moreover, the description of these akerites as given by Brögger,[1] with their rectangular zonal feldspars, applies closely to this rock. On the other hand, its relation to certain rocks which have been variously placed, sometimes among the syenites, sometimes among the diorites, is shown by the close agreement with the analysis of the rock from the Hodritsch Vale near Schemnitz. All these types clearly belong in a group by themselves, and, following the proposal of Brögger,[2] they may well be considered an intermediate group between the normal syenites and diorites and be called *banatites*, after the old name used by Von Cotta. Thus the rock of Yogo Peak, although here called a syenite, as under a broad grouping according to present ideas of rock classification it would undoubtedly be called, would for petrographic purposes be better designated a banatite. Its connection with the monzonite of Yogo Peak, as part of a single geologic mass, is extremely interesting, as it shows. as exhibited by nature itself, that grouping and connection which Brögger has suggested on theoretic grounds.

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[1] Syenitpegmatitgänge der sudnorwegischen: Groth's Zeit. f. Kryst., Vol. XVI, p. 51.

[2] Triadischen Eruptionsfolge bei Predazzo, p. 60.

Analyses of syenites.

Constituent.	I.	II.	III.	IV.
Silica (SiO_2)	61.65	59.56	61.73	1.027
Alumina (Al_2O_3)	15.07	17.60	17.45	.145
Ferric iron (Fe_2O_3)	2.03	2.90	5.94	.013
Ferrous iron (FeO)	2.25	3.38		.031
Magnesia (MgO)	3.67	1.87	2.29	.092
Lime (CaO)	4.61	3.67	4.52	.082
Soda (Na_2O)	4.35	4.88	3.12	.070
Potash (K_2O)	4.50	4.40	3.88	.048
Water (H_2O) at 110°	.26	1.37	1.16	....
Water (H_2O) above 110°	.41			
Titanic oxide (TiO_2)	.56	1.22	(?)	....
Chromic oxide (Cr_2O_3)	Trace.	×=.44	....	....
Manganese oxide (MnO)	.09	.03	....	....
Baryta (BaO)	.27	(?)	(?)	....
Strontia (SrO)	.10	(?)	(?)	....
Chlorine (Cl)	....	....	....	....
Phosphoric acid (P_2O_5)	.33	(?)	(?)	....
Sulphuric acid (SO_3)	....	....	....	....
Carbonic acid (CO_2)	....	....	....	....
Lithia (Li_2O)	Trace.	....	....	....
Total	100.15	101.32	100.09	....

I. Syenite, Yogo Peak, Little Belt Mountains, Montana. W. F. Hillebrand, analyst.

II. Syenite, akerite type, Vettakollen, South Norway. H. O. Lang: Nyt Mag. for Nat., vol. 30, p. 40. P. Jannasch, analyst.

III. Syenite, diorite, banatite, Hodritsch Vale near Schemnitz. K. R. von Hauer: Verhandl. K. k. Reichsanstalt, Wien, 1867, p. 82.

IV. Molecular proportions of No. I.

By assuming that all the alumina is in feldspar, and taking the equivalent of soda, potash, and lime for it, and then assigning sufficient ferrous iron to convert the ferric iron into magnetite, we may calculate the mineral composition with rather close approximation to truth; for the remaining lime, iron, and magnesia are to be divided between pyroxene and hornblende, which is readily done, while the excess of silica represents the quartz. This gives:

	Per cent.
Magnetite	3.1
Pyroxene	5.4
Hornblende	12.9
Anorthite	7.5
Albite	37.5

	Per cent.
Orthoclase	27.5
Quartz	6.1
Total	100.0
Components:	
Dark	21.4
Light	78.6
	100.0

The average plagioclase combining the above would be Ab_3An_1, but as a large part of the albite molecule is present in the orthoclase, the oligoclase present does not average nearly so much soda as this.

Local varieties of the syenite.—Toward the high east shoulder of Yogo Peak, which descends to a saddle on the ridge, the talus forming this slope shows a variety of the rock in which the plagioclase diminishes almost to the vanishing point, and the rock therefore assumes the character of a normal and typical syenite; in other respects its character is that of the type just described, and it can not, indeed, in the hand specimen, be distinguished from it. The variation, like all types at Yogo Peak, is probably local, but it has a certain petrologic significance, which will be treated of in another place.

At the prospect mining shaft which has been sunk not far from the contact on the south side of Yogo Peak, in the igneous rock, there occurs a light-colored rock which is another variation of the banatite in that it represents a more dioritic phase. The lath-like plagioclases clearly predominate over the alkali feldspar and form the main rock constituent. It is interesting to note in this variety that the hornblendes, although quite compact and appearing, on the whole, original, yet occasionally carry interior cores or fragments of pale-green diopside. What the exact relation of this diorite-like facies is to the shonkinite and monzonite, which are the main rock types of the vicinity, could not be learned, as it is not apparent at the surface, but it must certainly be quite limited in amount when compared with them.

Storr Peak.—The granite-porphyry of the great intruded mass of which Yogo Peak forms the western extremity passes again into more basic phases to the northeast. Thus, at the high point at the head of one of the forks of Dry Wolf Creek, near where the 110° 15′ meridian crosses the boundary of the igneous rocks, here called Storr Peak, the rock passes into a phase that is between a porphyry and a granular rock, and also a transition to syenite.

The hand specimen shows a rock that appears like a rather fine-grained syenite, gray in color, dotted with minute black specks of ferromagnesian minerals. In fact, megascopically, it exactly resembles the Yogo Peak syenite just described.

In the thin section the feldspar phenocrysts, which are almost entirely soda orthoclase with a very little oligoclase, are of uniform size and packed so thickly together that the groundmass is reduced to a very small amount, filling the little interspaces between them. It is a microgranite mixture of quartz and feldspars, and is quite fine grained. Some green hornblende, iron ore, and apatite complete the minerals. Such a rock is difficult to classify, as it is a connecting link between the granular and porphyritic structures, and also between the granite and syenite families. It appears best to place it here with the syenites, as its porphyritic character is seen only under the microscope, while the total amount of quartz is very small and is confined to the groundmass.

MONZONITE OF YOGO PEAK.

This name has been applied to a massive igneous rock occurring at Monzoni, in the Tyrol, and usually classified under the syenites, of which it has been considered a variety rich in plagioclase and in the darker ferromagnesian minerals, especially pyroxene. It has been shown in recent years that this type of rock is not confined to the vicinity of Monzoni, but occurs elsewhere in sufficient abundance to warrant the proposition that the name shall no longer be considered that of a mere variety of syenite, but of an independent rock group of the same order of significance as that of syenite and diorite, to be applied to those rocks in which the alkali and lime-soda feldspars are about equally balanced, thus avoiding the difficulties of classifying such rocks either with the syenites or the diorites.[1] In the former article on Yogo Peak, by Mr. Weed and the writer,[2] it was shown in the petrographic description that the type of rock forming the middle knob of the peak was of unusual character, in which alkali feldspars were of about equal amount with plagioclase, and the name "yogoite" was proposed for it. Later,[3] however, recognizing that "yogoite" is essentially the same rock as that from Monzoni and Predazzo, both chemically and in its mineral composition, the name "yogoite" was withdrawn for the older and better-known term. Rocks of this character have been found in several localities in Montana, and the number of occurrences in this portion of the Rocky Mountain area will no doubt be increased in the future. It can scarcely be doubted that many types of rocks hitherto placed under diorites or syenites by different petrographers, really belong in this general group, and that the future will show the type to be a not uncommon one. In the localities so far described—at Monzoni and Predazzo in Tyrol, at the Bearpaw Mountains, here at Yogo Peak, and also in the Highwood Mountains in Montana—the rock does not appear geologically alone and independent, but is accompanied by more feldspathic types on the one hand and by darker-colored, more basic, augitic varieties on the other. It is thus part of a differentiated complex, and considering the very medium chemical character it possesses, as a sort of petrographic mean, this should be expected.

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[1] Brögger, Eruptivgesteine des Kristianiagebietes, II, Predazzo.

[2] Am. Jour. Sci., 3d series, Vol. L, 1895, p. 467.

[3] Weed and Pirsson, Bearpaw Mountains of Montana: Am. Jour. Sci., 4th series, Vol. I, 1896, p. 357.

At Yogo Peak the rock occurs most typically and best exposed at the central one of the three prominent knobs forming the peak. On the one hand it grades into the banatite variety of syenite, previously described, which forms the eastern shoulder, and on the other hand into the shonkinite of the western outcrops and exposures.

The rock is divided by joints into short blocks, and is very firm and tough. On a freshly fractured surface it is rather dark gray, with a greenish tone, and appears of medium granularity. It is clearly seen to be somewhat mottled, by the contrast between the light-colored feldspathic portion and the darker-colored ferromagnesian minerals, and recalls in its appearance many diorites. The dark minerals appear to make up half the bulk of the rock. The reflection of light from numerous biotite cleavages of small size is also noticeable. The appearance of the rock is shown in Pl. LXX, *B*.

Under the microscope the minerals seen are iron ore, apatite, biotite, pyroxene, hornblende, plagioclase, alkali feldspars, and quartz.

The iron ore is not present in large amount, but is seen in scattered grains usually attached to pyroxene and biotite. The apatite is not abundant and shows nothing of special interest.

The pyroxene is a clear pale-green diopside of wide extinction angle and rather idiomorphic in form. It is comparatively free from inclusions, save those of iron ore and apatite; in a few cases some inclusions of a brownish substance, which may be glass, were seen. It is very fresh and unaltered, except for its connection with hornblende. It is the most abundant ferromagnesian mineral.

The hornblende is of the olive-green color usually seen in common hornblende, is strongly pleochroic, and is generally seen surrounding or attached to the diopside. It occurs in places penetrating the latter in small flakes or rods, and sometimes the diopside is quite spotted with these bits of hornblende. When in larger pieces it does not have any distinct idiomorphic form. All these facts go to show very clearly its secondary paramorphic character. Nowhere does it show those evidences of primary character which Iddings has so well described and figured in the intergrowths of hornblende and pyroxene in the diorite of Electric Peak.[1] An estimate based on the sections places the amount of hornblende at one-tenth that of the diopside.

The biotite is pleochroic, in tones of pale yellow and olive brown; basal sections are a deep umber brown. It is quite idiomorphic and has the usual apatite and iron-ore inclusions.

The plagioclase is rather variable; studies of it according to recent methods show that it is mostly andesine, in small part oligoclase, and even a little albite is present. It occurs in rather broad tabular forms, giving in general idiomorphic sections; sometimes it is seen in rather slender laths, which are always smaller than the tables mentioned above, and while they are generally Carlsbad twins they often show no albite twinning, or at best but one or two strips. They are invariably

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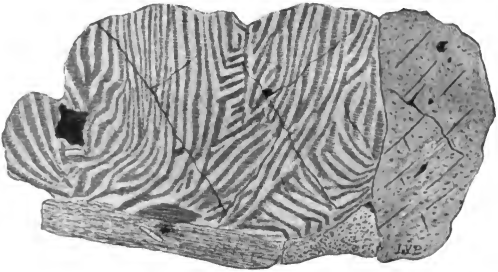
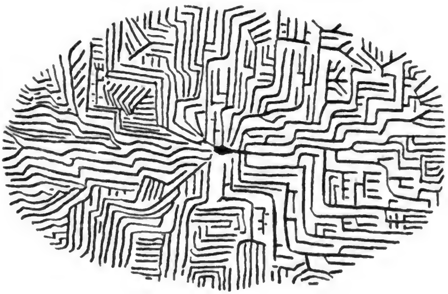
[1] Twelfth Ann. Rept. U. S. Geol. Survey, Part 1, p. 606.



A



B

A. INTERGROWTH OF TWO ALKALI FELDSPARS IN MONZONITE OF YOGO PEAK
B. SKELETON MAGNETITE IN OLIVINE OF SHONKINITE OF YOGO PEAK.

of andesine. The larger tables, on the contrary, always show albite twinning, usually in very fine lamellæ, and sometimes are not Carlsbad twins; they are more irregular in their composition, are sometimes zonally built with basic cores, and sometimes consist of varying irregular masses without any regular crystallographic or zonal arrangement, but with the albite twinning passing through as if the crystal were entirely homogeneous. Thus, in these crystals, while andesine is the most common proportion of the albite and anorthite molecules, they vary through oligoclase to albite.

The alkali feldspar is mostly a soda orthoclase, but this contains a microperthite-like intergrowth of another feldspar that is believed to be albite, but it is present in so narrow lamellæ that this could not be proved; moreover, it does not show the albite twinning. All that can be safely said of it is that it is another feldspar and not quartz. The intergrowths are not exactly like the usual microperthitic lamellæ of albite, but more nearly resemble micrographic intergrowths of quartz and orthoclase; they are shown in Pl. LXXI, *A*, in which they are seen very greatly magnified; it does not require a very high power to see them clearly.

The calculation of the chemical analysis shows that the total average alkali feldspar has the composition Or_1Ab_1, but the microscope shows that although this may be the sum total, there is considerable variability in the manner in which the albite and orthoclase molecules are arranged.

The structure of the rock is a purely hypidiomorphic granular one. There is a strong tendency for the ferromagnesian elements to be together, and also for little areas to occur in which plagioclase is very abundant, others in which it is nearly absent, unstriated alkali feldspar predominating. Thus, while taken in mass the composition of the rock is very homogenous, on a microscopic scale it is variable, and it is difficult to bring into the field of the microscope, except with extremely low powers, an area that would be typical of the rock as a whole. The alkali feldspar shows always a tendency to a broad, poikilitic character, tending to surround the other minerals. An extremely minute amount of interstitial quartz needs no further mention; its rôle as rock component is here without importance.

An analysis of the rock by Dr. Hillebrand is shown in the following table, and with it are given published analyses of four other monzonites from different localities. The older analyses are full of analytical errors and are not to be trusted. It will be noticed how nearly all these agree, and how little any one of them departs from the mean of the whole five given in No. VI. This mean may be taken then as the typical composition of a monzonite, especially as expressed in the nearest whole numbers and given in No. VIa. The feature of this chemical composition is the very medium character expressed throughout. In all respects the monzonites stand as a mean between the different rock groups.

Analyses of monzonites.

Constituent.	I.	II.	III.	IV.	V.	VI.	VIa.	VII.
SiO_2	54.42	52.81	52.05	51.00	54.20	52.89	53.0	0.907
Al_2O_3	14.28	15.66	15.02	17.21	15.73	15.58	16.0	.139
Fe_2O_3	3.32	3.06	2.65	2.41	3.67	3.03	3.0	.021
FeO	4.13	4.76	5.52	4.23	5.40	4.81	5.0	.057
MgO	6.12	4.99	5.39	6.19	3.40	5.22	5.0	.152
CaO	7.72	7.57	8.14	9.15	8.50	8.21	8.0	.139
Na_2O	3.44	3.60	3.17	2.88	3.07	3.23	3.0	.055
K_2O	4.22	4.84	6.10	4.93	4.42	4.90	5.0	.045
$H_2O-110°$	.38	.93	.35	.63	.50	.51	.5	....
$H_2O+110°$	.22	.16						
TiO_2	.80	.71	.47	.13	.40	.56	.5	....
Fl	....	Trace.	....	....	....	....	....	....
Cl	....	.07	.24	Trace.	....	.11	....	....
P_2O_5	.59	.75	.21	.33	.50	.47	.5	....
SO_3	....	Trace.	.02	.03	....	....	....	....
Cr_2O_3	....	Trace.	....	....	....	....	....	....
MnO	.10	Trace.	Trace.	Trace.	.70	....	....	....
BaO	.32	.24	.42	.34	(?)	.33	.3	....
SrO	.13	.09	.28	.14	(?)	.15	.2	....
Li_2O	Trace.	Trace.	....	....	....	....	....	....
Total	100.19	100.24	100.03	99.60	100.49	100.00	100.00	....

I. Monzonite of Yogo Peak. W. F. Hillebrand, analyst.

II. Monzonite of Beaver Creek, Bearpaw Mountains. Weed and Pirsson: Am. Jour. Sci., 1st series, vol. 50, 1895, p. 357. H. N. Stokes, analyst.

III. Monzonite of Highwood Peak, Highwood Mountains. Bull. U. S. Geol. Survey No. 148, p. 154. E. B. Hurlburt, analyst.

IV. Monzonite of Middle Peak, Highwood Mountains. Loc. cit. supra. E. B. Hurlburt, analyst.

V. Monzonite of Monzoni. Brögger: Eruptivegesteine, Predazzo, 1895, p. 24. V. Schmelck, analyst.

VI and VIa. Average of above analyses reduced to 100.

VII. Molecular proportions of No. 1.

If we make two or three assumptions, as follows: That the biotite is nearly or practically free from ferric iron, and agrees with the biotite of Monzoni (which has been analyzed) in this respect; that the replacement of magnesia by ferrous iron is similar in the minerals into which these enter, and that the amount of hornblende is one-tenth that of diopside, as shown by estimates made from the sections, we may calculate from the analysis and the table of molecular proportions given in No. VII the mineral composition of the rock. None of these assumptions is absolutely correct, but all of them must be approximately so;

hence the following table, while not absolutely accurate, must represent the composition rather closely:

	Per cent.
Magnetite	5.1
Biotite	12.1
Diopside	20.7
Hornblende	4.5
Anorthite	11.3
Albite	30.1
Orthoclase	16.2
Total	100.0
Andesine (An_2Ab_3)	27.2
Soda orthoclase (Or_1Ab_1)	30.4
Total feldspars	57.6
Total ferromagnesian minerals	42.4
Total	100.0

The amount of the albite molecule present is just sufficient to turn the anorthite into the andesine demanded by the microscopic study, and have enough left to convert the orthoclase into a soda orthoclase where the relations are as 1:1—a very common ratio for soda orthoclase, as, indeed, on chemical grounds we should expect. The calculation shows also that the plagioclase and alkali feldspar present are equal, and again shows the impossibility of logically classifying these rocks either as syenites or diorites. The large proportion of ferromagnesian minerals present, forming two-fifths of the whole, also shows the middle position occupied by this type.

SHONKINITE OF YOGO PEAK.

This name has been given to dark-colored basic granitoid rocks consisting chiefly of orthoclase (or alkali feldspar) and augite, but in which, unlike the syenites, which are feldspathic rocks, the augite predominates, producing an augitic or, as one might say, a gabbroid rock. Besides these chief components, olivine, biotite, and iron ore among the dark-colored minerals, and plagioclase among the light-colored ones, may be present, as accessory components, in considerable amount, but the orthoclase and augite are in all cases the determinant minerals. This type of rock is closely related to theralite, in that both are dark-colored basic augitic types and both are likely to occur associated with other types of rocks rich in alkalies, but theralite, the granular plutonic equivalent of the tephrites, has plagioclase and nephelite as its determinant white minerals.

The first shonkinite described was that from Square Butte, in the Highwood Mountains,[1] and later the occurrence at Yogo Peak was briefly mentioned.[2] This account it is now proposed to supplement with further details, and to mention another occurrence in this district.

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[1] Weed and Pirsson, Bull. Geol. Soc. America, Vol. VI, 1894, p. 389.

[2] Am. Jour. Sci., 3d series, Vol. L, 1895, p. 467.

Besides these occurrences in the Little Belt and Highwood mountains, shonkinite has been described from localities in the Bearpaw Mountains,[1] and it appears, as will be shown later, to occur at Monzoni, in the Tyrol, and doubtless other localities will be found as knowledge of the type becomes better known and petrographic research progresses.

At Yogo Peak the shonkinite forms the rock masses of the western end, abutting against the sediments, and it also occurs about 4 miles northeast, on the ridge running out in that direction from Yogo Peak. Here it is found in contact with the limestones at the head of one of the main branches of Running Wolf Creek.

The shonkinite rock does not possess the thick platy parting of the monzonite and syenite, but has an exceedingly massive character. The rock is very tough and breaks under the hammer with difficulty. On a fresh fracture it is of a very dark stone color, and at first glance recalls many coarse, dark gabbros. On inspection it appears that the quantity of ferromagnesian minerals is very large, and the eye is caught by the reflection of numerous plates of a dark-brownish biotite, which average several millimeters in diameter. With the lens a great abundance of small augites are also seen in the feldspathic constituent.

At places, especially toward the contact, there is considerable variation in the grain of this type; it sometimes occurs very much finer than the normal type mentioned above, and, on the other hand, at the extreme west end of the peak a variety is found that forms large, irregular masses, the rock being noticeable for the very large, spongy, biotite crystals which it carries. These biotites are at times 1 cm. across a cleavage face. They are made up of a number of smaller, nearly similarly oriented individuals mixed with other constituents. Although the mica is really subordinate in amount to the other minerals, it has the appearance of being predominant, and the rock seems at first glance to be almost wholly made up of these coarse biotite crystals, and has a very coarse-grained, curious appearance. Examination with the lens shows that although the biotite thus appears so important, it is merely because the crystals reflect the light from their cleavage surfaces, and thus seem more prominent than the other minerals; moreover they are very poikilitic, and are filled with augite grains. Thus the actual amount of biotite is less than that of either augite or orthoclase. The rock is shown in Pl. LXX, *C*.

Under the microscope the minerals seen are iron ore, apatite, augite, hornblende, biotite, olivine, plagioclase, and soda orthoclase.

Iron ore as an actual component of the rock is almost entirely wanting. In one phase a few scattered grains surrounded by coats of biotite were observed, but in the other sections, representing different phases and areas of the shonkinite mass, it may be said to be entirely wanting. This is a very striking feature for so dark and basic a type, which, as the analysis shows, possesses considerable of the oxides of iron. It is therefore clear that it has gone into the ferromagnesian minerals present, and the green color and character of much of the biotite indicates that it must approach lepidomelane in composition. It should also be stated that a very small amount of iron ore from the olivine resorptions, to be presently described, is also present, but this is in a way secondary and confined to these occasional minute areas.

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[1] Weed and Pirsson, Bearpaw Mountains of Montana: Am. Jour. Sci., 4th series, Vol. I, 1896, p. 351.

The apatite present in short stout crystals shows nothing of special interest. The amount of phosphoric anhydride in the analysis proves that 2.3 per cent of it is present, while the fluorine, in the absence of chlorine, shows it to be a fluor-apatite. The augite is a pale-greenish diopside like pyroxene of a very wide extinction angle. The prismatic cleavage is well developed; it has no other, and there is no trace of any diallage-like character. It is quite idiomorphic, especially in the prismatic zone, being bounded by the faces *a*(100), *m*(110), and *b*(010), which have generally about an equal development. The ends of the prisms are less well developed and are likely to be rounded off. The habit is short, thick, and columnar. It contains inclusions of biotite, and, less rarely, of glass or iron ore. These inclusions are infrequent. In size the crystals vary from one-tenth to 1 mm. in diameter.

Hornblende is not common, and its character and association are such as to lead to the belief that it is secondary, as described under the monzonite; its color, lack of definite form, and its association with pyroxene, are similar, but it is rather less in amount.

Olivine and its resorption bands.—The olivine, in the most basic type—that is, the one containing the coarse poikilitic biotite—is mostly very fresh and clear, but in a few places is altered to a yellowish-red micaceous substance—one of the well-known alterations of olivine which need not be further mentioned. The olivine has no good crystal outline, but is in irregular masses. It has, as inclusions, shreds of mica, sometimes an ore grain, and occasionally little darker shadow-like spots which, when examined with very high powers, are seen to be skeleton magnetites presenting wonderful patterns of intricate grating structures. They resemble somewhat similar growths which have been previously described by other petrographers. They are illustrated in Pl. LXXI, *B*.

The most interesting thing in regard to the olivines is the resorption phenomena they show. In the more basic and coarse-grained phase they are quite unaltered, except that they seem somewhat rounded, and where they come against alkali feldspar there is generally a band of green mica separating the two. From this character they pass, in other phases of the shonkinite, into types which are surrounded by zones, as is often the case in gabbros. The zones, however, are of somewhat different character from those seen in the gabbros. Here the olivine is surrounded by, first, a band of granules of a biaxial mineral of high refraction and rather low birefringence, whose general characters indicate it to be enstatite; the granules are rather small in size and too confused for absolutely positive identification, but this also seems most probable, considering the composition of olivine. Next to this comes a band of green biotite and then the alkali feldspar. The iron in the olivine separates out as iron ore in black grains. This process goes on until no olivine is left, and only a yellowish mica-like substance dotted full of ore grains shows the place of the core of the original crystal. Such a resorption phantom is shown in Pl. LXXIV, *A*. From this stage they may be traced gradually, by unaltered pieces of olivine, into the unchanged crystals.

But the most interesting point in regard to this change is that it is directly proportional to the amount of feldspar which the rock contains. In the most basic, least feldspathic type of shonkinite the olivines, as noted above, are unaltered or surrounded only by a band of biotite where they touch the feldspar; in the more feldspathic types they begin to be surrounded by the resorption bands, but there is generally, though not always, some olivine substance left. In the monzonite, a much more feldspathic phase of the Yogo Peak mass, these resorptions of olivine occur, but they are always resorptions (no olivine substance is seen) and they are, moreover, not nearly so common. In the syenite (banatite) certain groupings of iron ore and biotite suggest the same thing, but are not conclusive. It is indeed interesting as a speculation whether these olivines formed before differentiation took place in the mass or afterward.

The resorption zones, or "reaction rims," as they have been called, which occur around olivines in the plagioclase rocks have been so well described and their origin so fully discussed[1] that they need no further mention here; but it may be said that the idea that they could have been formed in the shonkinite under discussion by any dynamic metamorphic processes is not tenable for a moment; it does not even need to be discussed; we are dealing here with fresh rocks of a recent geologic period, breaking up through almost unaltered sedimentary beds.

When we consider the chemical composition of the minerals involved, the cause and character of these resorption or "reaction" phenomena in the shonkinite become quite clear. If we consider that olivine was one of the first minerals to separate out of the original magma, it was because a mineral of that composition was capable of forming and was insoluble in the resulting and residual magma or capable of existing in it. As the process of crystallization proceeded, however, and the pyroxene, biotite, etc., crystallized out, the residual magma became richer in alkalies and alumina, until it eventually solidified as alkali feldspar. When this stage was reached the olivine was no longer insoluble in the molten feldspathic magma, and, redissolving and the magma crystallizing, the following reaction took place:

$$\underset{\text{Olivine.}}{5(MgFe)_2SiO_4} + \underset{\text{Orthoclase.}}{K_2Al_2Si_6O_{16}} = \underset{\text{Hypersthene.}}{8(MgFe)SiO_3} + \underset{\text{Biotite.}}{K_2(MgFe)_2Al_2(SiO_4)_3}$$

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[1] Rosenbusch, Mass. Gest., 1895–96, p. 314.

That is, the olivine and orthoclase give rise to hypersthene and biotite, and very naturally the hypersthene, the mineral richest in magnesia, lies next to the olivine; while the biotite, rich in alkali and alumina, lies next to the feldspar. Thus it is very easy to see why, on purely chemical grounds, the formation of such zones and their composition may be both expected and explained.

It is to be noted that lime, which plays so important a part in the zones around the olivines in the gabbros, is entirely absent in the above. In one or two cases slender needles were seen in the outer zone, and it may be that lime has been present and a little hornblende formed, as in the gabbros. This is the exception, and not the rule, in the shonkinite.

Feldspars.—The feldspars in the shonkinite are somewhat variable, especially the plagioclase. This is sometimes present and sometimes wholly absent, and this within small areas, even within that of an ordinary thin section. It is usually in the form of laths, some very small and narrow, others broader and more columnar. It varies from interior cores as basic as a labradorite Ab_3An_4 to outer rims of andesine Ab_5An_3; both albite and Carlsbad twins are generally present. The noticeable feature of this plagioclase is its strong idiomorphic character, and this is especially noticeable when it lies embedded in the soda orthoclase. In some places, within a very minute area a considerable quantity of these plagioclase prisms will be heaped together, surrounded by broad regions quite destitute of them. Its total amount is small, and considered altogether it plays only the rôle of an accessory constituent. It seems to depend to some extent on the relation between pyroxene and biotite; thus, in the more basic phases, where augite is very abundant and its prisms thickly crowded, the plagioclase is almost wholly wanting, because the lime has all united with the magnesia and iron in the production of pyroxene, while in those areas where it is not so common the magnesia and iron combined with alumina and potash to form biotite, thus permitting the lime to enter into plagioclase with the soda.

The alkali feldspar ranks with the augite as the most important rock constituent. In sections perpendicular to the obtuse positive bisectrix—that is, approximately parallel to b (010)—the basal cleavage is easily seen and is usually good; at times a cleavage crosses this at 64°, which is probably parallel to the prism, a not unusual phenomenon in alkali feldspars. This gives the direction of the vertical axis and enables the section to be oriented, and it is then found that the extinction lies 10° in the obtuse angle—that is, is positive—and therefore the feldspar is a soda orthoclase. This is shown also by its watery, moiré appearance and by other phenomena which show that it is not a simple compound.

Chemical composition.—To show the chemical composition of the shonkinite there is given the analysis which has been made by Dr. Hillebrand; also some analyses of these rocks from other localities, all of which show the characteristics of the type—rather low silica, low alumina, high iron, lime, and magnesia, with moderate alkalies and the potash predominating over soda. In No. V is given the average of the first three analyses, and this may be taken as representing the composition of a typical shonkinite; the analyses vary from it but little.

Analyses of shonkinites.

Constituent.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
SiO_2	48.98	50.00	46.73	50.43	48.90	47.85	50.82	48.36	0.813
Al_2O_3	12.29	9.87	10.05	10.21	11.07	13.24	11.44	12.42	.119
Fe_2O_3	2.88	3.46	3.53	11.57	3.32	2.74	.25	5.25	.018
FeO	5.77	5.01	8.20		6.33	2.65	8.94	2.48	.080
MgO	9.19	8.31	9.27	5.58	9.06	5.68	14.01	9.36	.229
CaO	9.65	11.92	13.22	14.82	11.59	14.36	8.14	8.65	.173
Na_2O	2.22	2.41	1.81	1.48	2.15	3.72	1.79	1.46	.036
K_2O	4.96	5.02	3.76	3.70	4.55	5.25	3.45	3.97	.052
$H_2O-110°$	.26	.17	1.24	.87	1.13	2.74	.58	5.54	.031
$H_2O+110°$	.56	1.16							
TiO_2	1.44	.73	.78	Undet.	.98	......	.59	1.18	.017
P_2O_5	.98	.81	1.51	.70	1.10	2.42	.20	.84	......
SO_3	......	.02	......	......	......	......	......	......	......
CO_2	......	.31	......	.52	......	......	......	......	......
Cl	......	.08	.18	......	......	......	......	......	......
Fl	.22	.16	......	......	......	......	......	......	......
Cr_2O_3	Trace.	.11	......	......	......	......	.03	......	......
NiO	......	.07	......	......	......	......	......	......	......
MnO	.08	Trace.	.28	......	......	......	.19	.13	......
BaO	.43	.32	(?)	......	......	......	.06	.29	......
SrO	.08	.07	(?)	......	......	......	......	......	......
Li_2O	Trace.	Trace.	Trace.	......	......	......	......	......	......
Total	99.99	100.01	100.56	99.88	100.18	100.65	100.49	99.93	......
O=Cl, Fl	.08	.08	.04	......	......	......	......	......	......
	99.91	99.93	100.52	......	......	......	......	......	......

I. Shonkinite, Yogo Peak, Montana. W. F. Hillebrand, analyst.

II. Shonkinite, Bearpaw Mountains, Montana. Weed and Pirsson: Am. Jour. Sci., 4th series, Vol. I, 1896, p. 360. H. N. Stokes, analyst.

III. Shonkinite, Square Butte, Highwood Mountains, Montana. Weed and Pirsson: Bull. Geol. Soc. Am., Vol. VI, 1895, p. 414. L. V. Pirsson, analyst. As originally published MgO=9.68, but a recalculation of the analytical data showed that a slight error in calculation had been made, and that the MgO should be 9.27.

IV. Shonkinite, Monzoni. Lemberg: Zeitschr. d. Deutsch geol. Gesell., 1872, p. 201. Lemberg, analyst.

V. Average of I, II, and III.

VI. Malignite, Poohbah Lake, Ontario. Lawson: Bull. Geol. Dept. University of California, Vol. I, No. 12, p. 350. F. L. Ransome, analyst.

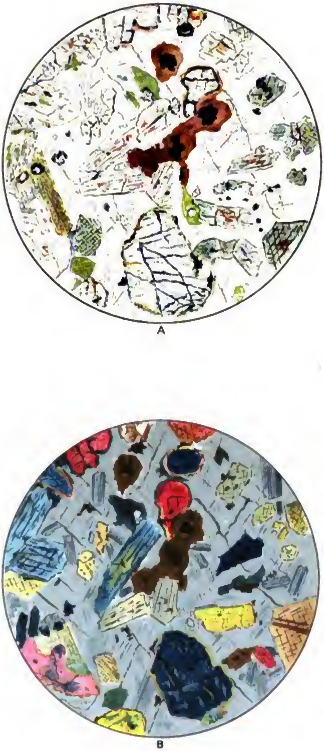
PLATE LXXII.

PLATE LXXII.

THIN SECTION OF SHONKINITE.

A, Shonkinite of Yogo Peak. Olivine (pale yellow), biotite (brown and olive), pyroxene (green), and soda orthoclase (white). Apatite and iron ore are also present, as well as a little plagioclase. Actual size of field 4 mm. multiplied by 19; section seen in natural light.

B, the same section seen in polarized light between crossed nicols. It shows the field occupied by a single large plate of orthoclase which incloses the other minerals, a common characteristic of this rock. The section here selected to show this does not contain quite the average amount of the dark ferromagnesian minerals.



L. V. P. del

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THIN SECTIONS OF SHONKINITE OF YOGO PEAK

VII. Lamprophyre, between South Boulder and Antelope creeks, Montana. Merrill: Proc. U. S. Nat. Mus., Vol. XVII, 1895, p. 670. L. G. Eakins, analyst.

VIII. Absarokite, dike south of Clark Fork, Wyoming. Iddings: Jour. Geol., Vol. III, 1895, p. 938. L. G. Eakins, analyst.

IX. Molecular proportions of No. I.

The shonkinite magma is that which is characteristic of the class of rocks which have been called lamprophyres. That this magma exists in other localities in a different mineralogic, structural, and geologic form is shown by the comparison of the analyses given in VII and VIII, the former a thick intrusive sheet, the latter a dike. The relation between shonkinite and absarokite has been already noted by Iddings.[1] In No. VI is given, for comparison, the analysis of a rock described by Lawson[2] under the name *malignite*. Mineralogically it is closely related to shonkinite, in that pyroxene and orthoclase are the prominent constituents; it differs in the presence of nephelite and in the character of the pyroxene, which is ægirite-augite, and these differences are caused by the larger amount of alkalies, especially of soda. Rosenbusch[3] places it under the shonkinites, including both in the theralite family.

Structure and classification.—The structure of the Yogo Peak rock is purely hypidiomorphic granular, and it has all the characteristics of a plutonic rock. The most striking and dominant microscopic feature is the poikilitic character of the orthoclase, which occurs in broad masses enveloping the other minerals and evidently the latest product of crystallization. This is shown in the figures given on Pl. LXXII. Lawson[4] mentions it as being also a characteristic of malignite.

From a consideration of the molecular proportions given in No. IX of the table of analyses and the results of the study of the thin sections, it is estimated that the rock contains, on the average, by weight—

	Per cent.
Pyroxene	35
Biotite	18
Olivine	7
Hornblende, apatite, etc	5
Andesine	10
Soda orthoclase	25
Total	100
Dark constituents	65
Light constituents	35
Total	100

This, of course, is not accurate, but the control is sufficient to make certain that the variation in the more doubtful constituents can not be more than a few per cent either way.

A mere inspection of the above table shows that this rock can not be classed with existing rock groups, and that its erection into a new group is justified. But its occurrence in other localities and the acceptance of the group by other petrologists are already matters of history and render any further comment on this point superfluous.[1] It must be stated, however, that the persistent appearance of quantities of biotite in all these cases, due doubtless to the large amount of MgO and K_2O in the magma, renders this mineral a much more constant feature of the rock type than was supposed would be the case when the original specimen from Square Butte was described.

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[1] Jour. Geol., Vol. III, 1895, p. 953.

[2] Bull. Dept. Geol. Univ. Cal., Vol. I, March, 1896, pp. 337–362.

[3] Mass. Gesteine, 3d ed., 1895–96, p. 1303.

[4] Loc. cit.

Shonkinite at head of Running Wolf Creek.—This occurrence, which has already been mentioned in the description of the Yogo Peak mass, has also been studied in thin section, and excepting the fact that none of it has been seen to carry any plagioclase and that the soda orthoclase is a little more abundant, it so exactly resembles the type already described that no further mention is necessary.

Shonkinite of Otter Creek.—Besides the occurrence of shonkinite at Yogo Peak, there is another in the region of the Little Belt Mountains which deserves brief mention. It forms the large heavy mass intruded in the Upper Carboniferous beds on Little Otter Creek, about 2 miles or so above its junction with the main Otter stream. The mass is exposed at least 300 feet above the creek, and the outcrops, which are very columnar, extend in a long line, suggesting a sheet which must be extremely thick. The road quarry at one point has exposed quite good fresh material.

In the hand specimen the rock is very dark gray and moderately fine grained, the components running from 1 to 2 mm. in diameter. In the section it shows the same minerals mentioned above for the Yogo Peak shonkinite, but the amount of olivine, which is very fresh and has no reaction rims, is considerably greater, while biotite is much less. The amount of andesine is also less, only an occasional minute prism being present. The orthoclase as usual cements the other minerals. The rock in other respects so closely conforms to the description already given that it needs no further mention.

PINTO DIORITE OF NEIHART.

This rock forms the great massif intruded in the crystalline schists at Neihart, and hence it is there one of the most prominent rocks; the slopes north and east of the town are covered with bowlders of it, and it is equally prominent in the Carpenter Creek Gulch. Many mines are connected with it, and its striking appearance makes it well known among the mining population in the vicinity.

The rock is noteworthy for its bizarre appearance, which is best seen on a large scale on some cliff wall or smooth surface of a large

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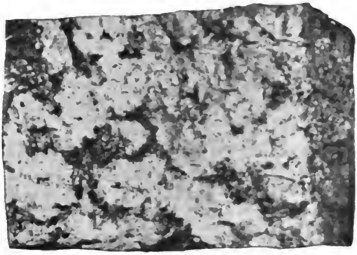
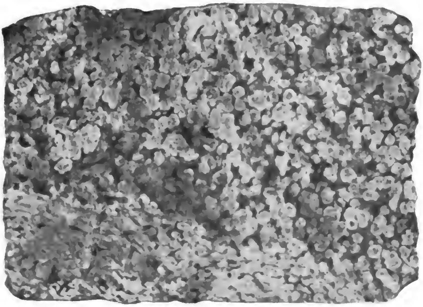
[1] In his review of the original paper on Yogo Peak by Mr. Weed and the writer (Neues Jahrbuch, 1896, Vol. II, p. 442), H. Behrens quotes none of the analyses, omits all mention of the presence of orthoclase in the shonkinite, mentions especially the kind of plagioclase, states with emphasis that it resembles gabbro, and thus produces a totally false impression that only an ordinary gabbro had been described and decorated with a new name, an idea which anyone may see is patently wrong by reading the original description and observing the analysis.



A



B

A. DIORITE OF NEIHART—PINTO DIORITE.
B. VARIOLITIC MINETTE OF SHEEP CREEK.

From photographs (natural scale) of actual specimens.

outcrop, where it has a mottled appearance, due to ovoid masses of feldspar which vary from half an inch to an inch or more in diameter, and which lie so thickly scattered that they constitute the main portion of the rock, the interspaces between them being much less in bulk amount; indeed, they run into one another in many places, leaving only rudely cusp- or lune-shaped spaces between them. Neither are these feldspar bodies always ovoid; sometimes they are curved, bent, drawn out, elongated, and otherwise distorted, but the average shape inclines to the ovoid character. The interspaces between them are filled with a greenish-black ferromagnesian mineral, and it is this strong contrast of these white spots on a black background that gives the rock the peculiar mottled appearance that is so striking, especially when seen on a large scale. When seen in this way the rock has also a gneissoid appearance, as the ovoid feldspar spots have their longer axes in one common direction, as a rule, and they are likely to succeed one another in lines, thus suggesting gneissoid structure. In the hand specimen it can be scarcely observed—the scale is too great—but an illustration is given in Pl. LXXIII, *A*.

This mottling produces also the effect of a huge coarse porphyry, the white spots appearing like phenocrysts. The appearance is, however, deceptive, for the rock is not a true porphyry, as will be shown later. The structure might be termed pseudoporphyritic. When the rock is examined closely, and especially with the lens, it is seen that the apparent phenocrysts—the white feldspar masses—are not made up of a single feldspar crystal, though they are likely to contain one feldspar mass that is larger than all the rest. They are of a pale-green or gray color. The dark material filling the interspaces is in greater part a black lustrous hornblende, which has a somewhat schistose arrangement. Occasionally a shining leaf of biotite is seen among the hornblendes.

Microscopic characters of diorite.—In thin section under the microscope the minerals seen are apatite, iron ore, biotite, hornblende, plagioclase, and orthoclase; a very little sericite and calcite from alteration products of the plagioclase are also present. The apatite in small prisms lies mostly embedded in the hornblende. The iron ore is in small anhedra and is limited in amount. Biotite is of the usual dark-brown pleochroic variety; it is variable in amount; sometimes there is considerable to be seen in the section, at other times it is almost wanting. This is the case in the sample analyzed.

The hornblende is in small formless masses which tend to produce prismoid bodies which are more or less extended in one direction, thus aiding in the effect of schistosity. These prismoids are heaped together in clusters, without any other included mineral except apatite, and define the white feldspar areas. It is of the type of common hornblende, with its pleochroism of deep grass-green, olive green, and yellow.

The plagioclase is in formless interlocking grains, always twinned according to the albite law, almost never according to the pericline law. No Carlsbad twins were seen in spite of careful search. There is considerable variation in the size of the grains. In sections perpendicular to 010 the maximum extinction found was 24°, which would indicate a basic andesine, according to the statistic method. There are no zonal growths to be seen among these feldspars; they are apparently all homogeneous and similar throughout. The calculation of the chemical analysis shows that they have the composition $Ab_{10}\ An_7$, which confirms the measurement given above; the plagioclase is basic andesine.

Orthoclase is also present in rather small amount, and is generally interstitial in character between the plagioclases. Both of the feldspars are more or less turbid from leaves of sericite, which as usual develops mostly along the cleavage cracks. The analysis shows that a little trace of a carbonate is present, and this may be due to some calcite deposited along cracks; none was recognized in the sections. A few minute grains of quartz were detected along with the orthoclase.

Chemical composition.—The composition of this diorite is shown in No. 1 of the adjoining table, as made by Dr. Hillebrand.

Analyses of diorites.

Constituent.	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.
SiO_2	55.13	53.48	58.05	52.05	55.53	58.05	58.63	55.54	.919	55.80
Al_2O_3..........	20.27	19.35	18.00	17.96	16.80	15.46	16.23	15.64	.197	17.44
Fe_2O_3	1.52	2.37	2.49	4.09	4.06	1.69	1.91	1.19	.010	2.59
FeO..........	4.29	4.90	4.56	6.33	3.35	5.09	4.20	7.13	.060	4.67
MgO..........	1.80	3.67	3.55	5.03	3.00	4.84	4.28	4.84	.045	3.59
CaO	7.05	7.55	6.17	8.64	6.96	6.94	6.59	5.67	.126	7.13
Na_2O..........	4.31	4.07	3.64	2.99	4.31	2.86	3.51	3.17	.069	3.67
K_2O..........	2.84	1.41	2.18	1.61	3.57	2.14	2.09	2.28	.030	2.26
$H_2O - 110°$....	.14	.16	.86	.97	.09	.10	.15	2.93	.060	1.13
$H_2O + 110°$....	.95	.80			.55	2.02	1.17			
TiO_2	.74	1.07	1.05	......	.95	.72	.74	1.24	.009	.88
P_2O_5	.40	.62	.17	.31	.47	.16	.20	undet	.003	.33
CO_2..........	.26	.08	......	......	.09	none.	none.	undet.	......	......
MnO..........	.13	.06	none.	.43	.16	.14	.11	(?)	......	.17
BaO	.06	.19	undet	undet.	.13	.07	.06	undet.	......	.11
SrO..........	.11	.11	undet.	undet.	.11	trace.	trace.	undet.	......	.09
Li_2O	trace.	trace.	none.	......	trace.	trace.	trace.	......	......	......
Total....	100.00	99.89	100.79	100.41	100.17	100.28	99.93	99.63	......	99.88

I. Diorite, Carpenter Creek, near Neihart, Montana. W. F. Hillebrand, analyst.

II. Quartz-diorite, Sweet Grass Creek, Crazy Mountains, Montana. Bull. U. S. Geol. Survey No. 148, p. 143. W. F. Hillebrand, analyst.

III. Diorite, Electric Peak, Yellowstone Park. Iddings: Twelfth Ann. Rept. U. S. Geol. Survey, Part I, p. 577. W. H. Melville, analyst. Includes 0.07 SO_3.

IV. Augite-diorite, Stony Mountain, Ouray County, Colorado. Bull. U. S. Geol. Survey No. 148, p. 180. L. G. Eakins, analyst.

V. Diorite, La Plata Mountains, Colorado. Bull. U. S. Geol. Survey No. 148, p. 181. W. F. Hillebrand, analyst. Includes 0.04 FeS_2.

VI. Diorite, near Sonora, California. Bull. U. S. Geol. Survey No. 148, p. 218. W. F. Hillebrand, analyst.

VII. Diorite, Captains Bay, Unalaska Island. Bull. U. S. Geol. Survey No. 148, p. 232, with 0.04 FeS_2 and 0.02 NiO. W. F. Hillebrand, analyst.

VIII. Diorite, Lampersdorf in Silesia. Cf. Zirkel, Lehr. Petrog., Vol. II, p. 485. Hampe, analyst.

IX. Molecular proportions of No. 1.

X. Average of analyses I to VII, inclusive.

For the sake of comparison, a number of other analyses of diorites are quoted, mostly from Bulletin 148 of the United States Geological Survey. It is interesting to observe how nearly alike they are and how clearly they show the characteristic magma composition for a typical diorite—that is, medium silica, high alumina, medium iron and magnesia, high lime, moderate alkalies, with soda predominating strongly over potash. The alumina, lime, and soda condition the appearance of the plagioclase; with an increase of magnesia and iron the ferromagnesian minerals would become more prominent and the rock would pass into the gabbros; with potash predominating over soda, biotite and orthoclase would become prominent and it would pass into the monzonites. The analyses here given are the best that have been made of diorites; most analyses are very crude and untrustworthy, especially as showing the relation between alumina and magnesia, oxidation of the iron, etc. One of the best, taken from Zirkel, is given under VIII. The average of these seven analyses, given in X, may be taken as representing a typical diorite magma; as such it may be of value for comparison. Undoubtedly a portion of the water in the analyses is not secondary, but original, and comes from the biotite and hornblende.[1]

From the molecular proportions given under IX of the table we may approximately calculate the mineral composition of the rock by reckoning the feldspars from the alumina, the iron ore from the ferric iron, and the hornblende from the magnesia, a little correction being applied for the small amount of biotite, apatite, etc., but as the others are the chief minerals the error is small and can not materially affect the result. From this calculation we find that the rock contains—

	Per cent.
Iron ore	2.5
Biotite, apatite, etc.	3.5
Hornblende	13.0
Andesine	63.5
Orthoclase	17.5
Total	100.0

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[1] Cf. Granitit von Durbach, Sauer: Mitt. d. Grossh. Baden. Geol. Landesanst., Bd. II, pp. 251-255.

The feldspars present are, Ab=36.2, An=27.5, Or=17.5. The dark minerals are 19 per cent; the light minerals 81 per cent.

Structure and classification.—The remarkable feature of this rock is its structure, which is ocellar or pseudoporphyritic. It is remarkable to find all the feldspars collected into such lumps or eyes, and the interspaces filled with hornblende. It recalls the ophitic structure of diabases in which the feldspars are idiomorphic and the augite fills the interstices between them. The rock, it is true, has been subjected to severe dynamic pressure, the geologic evidence in the field and its appearance in the hand specimen and under the microscope agreeing on this point. The hornblende, however, shows no evidence of this, but the andesine is cracked and granulated and the albite twinning lamellæ are curved and broken. But it is difficult to see how pressure and shearing could have produced this structure if there had been an ordinary diorite to work upon. It is very much what would be produced if a corsite,[1] with its orbicular masses, were crushed and sheared. But here there is so marked a separation of the light and dark minerals that one feels compelled to assume that this must be an original character—produced in the magma, perhaps, as an ophitic structure on a huge scale which was afterwards crushed and broken down by the dynamic forces. With the facts at present at hand regarding the rock, it seems useless to speculate further upon the origin of this structure, but so far as the author knows it has not been elsewhere described, and he desires to call the attention of petrographers to it in the hope that some light may be thrown upon it.

Contact facies of diorite.—Where the diorite comes in contact with the crystalline schists, and especially where it penetrates them in apophyses, it shows a marked endomorphic contact modification. The rock becomes of quite fine grain, compact, very dark in color, and in some places has scattered through it numerous flat tabular feldspar phenocrysts; it is here a true porphyry. On a freshly broken surface these feldspar phenocrysts are dark and not especially noticeable, but on a weathered surface they are white and strongly contrasted against the background, and it is here seen that they have a strongly pronounced flow structure, the flattened tables being arranged in lines, curves, etc. The groundmass, or the rock devoid of phenocrysts, is very dark and glitters with innumerable mica scales, so that it has a somewhat minette or kersantite-like appearance.

Under the microscope the minerals seen are iron ore, apatite, titanite, biotite, hornblende, andesine, orthoclase, quartz, and sericite.

The iron ore, the apatite, and the occasional titanite in grains offer nothing unusual. The biotite is not abundant, and in considerable areas is entirely wanting, as in the main diorite. Hornblende is present in considerable amount, much greater than in the diorite, and is in rounded grains or small masses. The feldspar phenocrysts are almost entirely converted into masses of sericite, or at least into a fine, scaly, micaceous, colorless mineral of high birefringence, and it is difficult to say more about them, except to determine, from unaltered scraps, that in all cases they are a plagioclase, and a rather basic one. They are in strong contrast to the rest of the rock, which is very fresh, and the feldspars of the groundmass are andesine, with a subordinate amount of orthoclase and a very little interstitial quartz. The groundmass feldspar is dotted through with small grains of iron ore.

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[1] Orbicular diorite or Napoleonite of Corsica. Cf. Zirkel, Lehrbuch der Petrog., Vol. II, p. 471.

The most interesting thing about this contact rock is its structure and petrologic position. The structure is the sugar granular one characteristic of aplites—that is, it is panidiomorphic in the sense of Rosenbusch; all the grains, feldspar and hornblende, have an isometric development. The rock has, however, compared with the main diorite, a very considerable enrichment of the dark minerals; in the hand specimen, aside from the type which has phenocrysts, it looks like a kersantite—that is, it appears like a lamprophyre or is melanocratic in the sense of Brögger.[1] This enrichment in the dark minerals is of very common occurrence in intruded igneous masses, and need not be further dwelt upon beyond the influence it has upon the character of the rock produced. Aside from the type with rather abundant thin, flat phenocrysts of feldspar, one could call this variety of diorite a type of the *spessartite* of Rosenbusch,[2] with the description of which it very closely agrees. Rosenbusch speaks of these rocks as sometimes having a holocrystalline porphyritic structure, and if we accept the view that a lamprophyre can contain feldspar phenocrysts, this variety of the rock would be a *spessartite-porphyry*. The occurrence of a lamprophyric border facies of an intruded diorite is of great interest. The type, which is purely lamprophyric, without phenocrysts, is in places quite gneissoid from a parallel arrangement of the components. What the quantitative relation of the facies which is porphyritic bears to that which is not, could not, from the nature of the outcrops, be ascertained.

APLITES.

All portions of the rock masses composing Yogo Peak—the huge heavy black knobs, monoliths, and masses of shonkinite forming the western end, the masses and rock heaps of monzonite forming the middle portions, and the platy débris and slide-rock areas of the banatite-like syenite of the eastern shoulder—are everywhere cut by narrow veins, or rather dikelets, if they may be so termed, of a light-colored aplitic rock. In places these veins are very numerous, and as they resist weathering much better than the basic rock which they cut, they are likely to project as ribs or slight ridges on the rock faces. The cut shown in fig. 73 is a drawing of a rock slab about 3 feet square, approximately drawn on the scale of $\frac{1}{20}$, and this shows how numerous these little dikes are. They vary in width from a fraction of an inch to perhaps 2 feet or more, and their length can not be told. They clearly represent a later intrusion of more acidic feldspathic magma after the main masses had cooled, crystallized, and broken through contraction into innumerable fragments.

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[1] Eruptivgesteine Kristianiagebietes; III, Ganggefolge des Laurdalits, p. 262.

[2] Mass. Gesteine, 3d ed., 1895–96, p. 532.

These dikes are composed of a fine-grained nonporphyritic rock of a pale-red color. Under the microscope it is seen to be composed of the same minerals as the syenite and monzonite which it cuts; that is to say, pale-green diopside surrounded by mantles of common green hornblende which appears paramorphic in character, shreds of biotite, a very little iron ore and apatite, a very small amount of oligoclase, a soda orthoclase, which is the chief mineral, and a little interstitial quartz. The structure is granular allotriomorphic or panidiomorphic, as one chooses to regard it, characteristic of aplitic rocks, where the grains are of general isometric character, without distinct crystal form and nearly of a size, perhaps 0.5 mm. in diameter.

The iron ore is a mere trace, the iron appearing almost wholly in the ferromagnesian minerals. These latter are in proportion to the white components about as in the banatite-like syenite of Yogo Peak, in which the dark are to the light components as 1:5; that is, 20 per cent of the former to 80 per cent of the latter, which in this case is almost entirely soda orthoclase, as the amount of plagioclase is very small, not nearly so great as in the banatite.

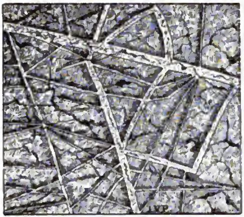
FIG. 73.—Rock surface at Yogo Peak, showing aplite dikelets.

Banatite-aplite variety.—In one of the dikes the rock contains dark-colored angular inclusions which, so far as can be determined, seem to consist of fragments of the more basic shonkinite-like rocks through which the magma has pressed upward. This dike is also of interest in that, like the banatite, it contains a large proportion of plagioclase, and the feldspar minerals have the same tendency to a square, tabular, idiomorphic form. Between these the minerals, orthoclase, and quartz filling the interspaces are rather finely granular, and there is thus a tendency to a porphyritic structure. The diopside has almost wholly given place to hornblende, and it is indeed an interesting fact that the diopside in the Yogo Peak rocks changes into hornblende in direct ratio with the increase of silica.

The Yogo Peak massif is also cut by dikes of granite-porphyry, but these are mentioned in connection with that rock (p. 502).

SHEARED APLITE OF NEIHART.

The crystalline schists around Neihart below the Belt quartzite are in many places filled with granitic injections which appeared as dikes, etc. In the severe dynamic pressures and shearing to which these rocks have been subjected, these igneous rocks also have suffered. This is well illustrated by an aplite from near the Moulton mine which has taken on a gneissoid structure. When the thin section of one of these is studied under the microscope, it is seen that the minerals no longer have the forms characteristic of them in unaltered igneous rocks.

The quartz is strewn out in angular fragments, which extend in long lines, and the larger pieces have an undulatory extinction, showing optical strains due to pressure. The alkali feldspar also shows certain peculiarities. It is mostly a microcline, but the grains, instead of being either orthoclase or microcline in clear, well-defined areas, such as, for instance, one finds in many rocks, like some of the elæolite-syenite of Litchfield, Maine, are indefinite and indeterminate between orthoclase and microcline. Some larger grains of feldspar extinguish uniformly, are untwinned, and appear to be homogeneous orthoclase and remnants of larger crystals, perhaps phenocrysts. In others, however, there is an undulatory rolling extinction which is much like that in the quartzes. Unlike that in the quartzes, however, it often starts from certain spots and rolls in several directions, and one may trace such areas into those of weakly defined microcline, and these into more perfect material. Yet the microcline itself is never sharp, clean, and well defined, as one finds it in pegmatite dikes; it, too, has a rolling extinction. These transitions occur not only in different grains but in the same grain, and every gradation may be traced in such a grain, from homogeneous orthoclase into areas of undulatory extinction, and from these into the microcline.[1]

Origin of the microcline.—The whole appearance of these two minerals is such that one feels forced to believe that the feldspar can not be in its original condition, but has suffered a change of some sort—that either the orthoclase or the microcline is not the original mineral. Moreover, the fact that these appearances occur in a rock that has been much sheared, has, of course, a great tendency to strengthen this opinion, though it is not the cause of it. At all events, it may be set down as almost certain that one or the other is not the original mineral, but whether the microcline has been changed into orthoclase, or vice versa, is not easy to say. Microcline occurs in aplites, but it is far less common than orthoclase; the largest feldspars in the rock are orthoclase; the smallest fragments, or those most crushed, are invariably microcline. The microcline itself is ill defined in character, and these appearances lead to the belief that it is the secondary mineral. Moreover, it is a common phenomenon that in a variety of minerals twinning is produced by pressure, and not the reverse; and it would also be natural to expect that in such a crushing process, if a substance were dimorphous, it would have its symmetry reduced from a higher to a lower state. Even if one believes that orthoclase is only submicroscopic microcline, it would be easy to understand that an extremely complicated system might be reduced to a simpler one. The general prevalence of microcline in the crystalline schists and its common association with gneissoid structure are well known. In the New Haven area granites occur, which in those places where they have suffered dynamic metamorphism contain microcline of the same character as that described above. There seems, therefore, very clearly to be, in certain cases, some casual relation between the occurrence of microcline and dynamic metamorphism; whether primarily induced by the pressure or other causes which the dynamic metamorphism has set at work, is not easily told. Its occurrence in pegmatites and in certain unaltered igneous rocks rich in alkalies, is of a quite different character from this, and is not here considered.

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[1] See also Zirkel, Lehrbuch der Petrog., 2d ed., Vol. II, p. 4, 1894.

GRANITE-SYENITE-APLITE OF SHEEP CREEK.

The sheets of minette intruded in the Cambrian shales at the head of Sheep Creek, and whose petrology is described later in this work, are cut in a number of places by narrow dikes of a white feldspathic rock from 6 to 12 inches in width, which has partly the aspect of a porphyry, partly of an aplite, and whose mineral character shows it to lie between the granite and syenite groups. The cutting made for the roadway along Sheep Creek has well exposed these narrow dikes in one or two places, and they are clearly seen cutting the dark-colored shales and intruded sheets of minette. The latter has a soft, decayed, smooth character in its exposure, across which the dikes break irregularly, with crooked courses and with very massive jointing for so small dikes.

The rock in the hand specimen is gray, and appears like a very fine aplite of syenite aspect, rather thickly spotted with very small formless phenocrysts of feldspar which are not much larger than the groundmass in which they lie.

In thin section this groundmass is seen to be made up of alkali feldspar and quartz in a rather coarse microgranitic structure, and is brown and turbid with kaolin. In it lie scattered small phenocrysts of oligoclase, orthoclase, and green hornblende, with fewer of biotite. The oligoclase has an average character of Ab_3An_1, and this makes the orthoclase a soda orthoclase of the composition Or_1Ab_1. An analysis of the rock by Dr. W. F. Hillebrand resulted as follows:

Analysis of granite-syenite-aplite from Sheep Creek, Little Belt Mountains, Montana.

Constituent.	I.	II.
SiO_2	66.29	1.105
Al_2O_3	15.09	.146
Fe_2O_3	1.37	.008
FeO	1.17	.016
MgO	2.39	.060
CaO	2.38	.042
Na_2O	3.96	.064
K_2O	4.91	.052
$H_2O+110°$	.60	.033
$H_2O-110°$	.39	....
TiO_2	.27	....
P_2O_5	.15	....
CO_2	.45	.010
MnO	.06	....
BaO	.30	....
SrO	.07	....
Li_2O	Trace.	....
Total	99.85	....

I. Percentages.
II. Molecular proportions.

This composition recalls closely that of some of the granite-porphyries of the laccoliths of this region, as is shown later. From this analysis and the study of the section we may approximately calculate the mineral composition as follows:

	Per cent.
Magnetite	2.0
Biotite	3.3
Hornblende	7.4
Oligoclase	16.2
Soda orthoclase	47.6
Quartz	18.4
Kaolin	4.1
Calcite	1.0
Total	100.0

The occurrence of this aplitic dike, although in texture it might equally well be classed as a porphyry, is from a genetic point of view of great interest, since we find it cutting the minettes which form so prominent a feature of this part of the district, and itself having the composition of the great masses of acid rock, the granite-porphyries of the laccoliths of the region, while the minette has very nearly the composition of the shonkinite of Yogo Peak.

CHAPTER III.

ACIDIC FELDSPATHIC PORPHYRIES OF THE LACCOLITHS, DIKES, AND SHEETS.

INTRODUCTION.

The classification and consequently the arrangement and description of these rocks offer some difficulties. Not only do they differ in their mode of occurrence geologically, but there are many transitional types among them, the transitions being in several cases of much more importance locally than the more commonly known types of such rocks, and, further, these transitions occur not only in different masses, but often in the same mass. On the other hand, the description, according to geologic occurrence, would involve a vast amount of repetition. It has seemed best, therefore, to describe the rocks under the headings of well-recognized types, and discuss the transitional forms under them.

The types of acid porphyries occurring in the district are granite-porphyry, granite-syenite-porphyry, syenite-porphyry, syenite-diorite-porphyry, diorite-porphyry, rhyolite-porphyry (quartz-porphyry), and trachyte (bostonite).

GRANITE-PORPHYRY.

From a geologic point of view this rock is one of the most important in the Little Belt Mountains, as it forms many of the largest laccoliths and intrusive masses and comprises many of the sheets and dikes. The large amount of material these afford for study is grouped and discussed under several types of this rock which are of local importance, and to which, therefore, local names have been given, such as the Wolf Butte, the Barker, the Yogo Peak, and the Carpenter Creek types.

WOLF BUTTE TYPE.

One of the most important occurrences of granite-porphyry is the large area of Wolf Butte and the peak southward from it. This great laccolith is intrusive in the shaly Cambrian beds below the Lower Carboniferous, whose heavy limestones it has upraised and displaced. The mass has been much eroded and cut into, so that the prevailing type of rock is clearly seen. It is of a pale-gray color, of a rather dense groundmass, thickly sprinkled with white feldspar phenocrysts from 3 to 5 mm. in diameter, with occasional ones of about 20 mm. in length and of tabular form; among them one sees, less frequently, dark-gray phenocrysts of quartz from 2 to 8 mm., averaging 3 to 5 mm., in diameter. The appearance of the rock is rather dull and lusterless, especially the feldspar phenocrysts, as if considerably altered; some of the larger ones, however, are clear, transparent, and of sanidine-like character; these are unstriated and are of orthoclase. A very few small black tablets of biotite complete the list of megascopic minerals. The rock carries inclusions of a mica-syenite of rather fine grain which may be several centimeters in diameter.

Under the microscope the quartz phenocrysts show the common phenomenon of rounding and of absorption embayments, and they are frequently surrounded by coronæ of the groundmass. The large phenocrysts and most of the small ones are of orthoclase, many of the smaller are of oligoclase, and small penocrysts of the latter are intergrown in the large crystals. The biotite is of the usual pleochroic brown variety; a small amount of iron ore is present.

The groundmass is a very fine grained mixture of quartz and alkali feldspar of distinct microgranitic structure, and the whole rock is thus seen to be a common and well-known type; it is, in fact, a typical granite-porphyry in all respects, and it is to be regretted that better material could not be procured for the analysis. The dull appearance of the rock is seen under the microscope to be due to the presence of considerable kaolin, which occurs chiefly in the groundmass, rendering it turbid and brown in color. A little calcite, and probably muscovite also, is present.

An analysis of this type has been made by Dr. W. F. Hillebrand and is herewith given.

Analysis of granite-porphyry from Wolf Butte, Little Belt Mountains, Montana.

Constituent.	I.	II.
SiO_2	69.68	1.161
Al_2O_3	14.97	.145
Fe_2O_3	.79	.005
FeO	.34	.005
CaO	2.10	.016
MgO	.66	.036
Na_2O	3.38	.054
K_2O	4.40	.047
H_2O — 110°	1.09	
H_2O + 110°	.92	.050
TiO_2	.28	
P_2O_5	.17	
CO_2	.88	.020
SO_3	Trace.	
Cl	Trace.	
MnO	Trace.	
SrO	.06	
BaO	.14	
Total	99.86	

I. Percentages.
II. Molecular proportions.

The composition is that of a typical magma of the granite family, and it needs no further comment. The amount of water and carbonic acid shows that the rock is not very fresh; the amount of calcite seen in the section would not account for the amount of carbonic acid, but as the rock is greatly cracked, making it difficult to obtain a fair-sized hand specimen, and as the laccolith has solidified under a heavy cover of limestones, since eroded away, it seems clear that these joints have become filled with secondary films of calcite, which might not show in the sections and yet be sufficient to account for the carbon dioxide.

From the molecular proportions given in the second column, we may readily calculate the mineral composition to be:

	Per cent.
Iron ore	1.13
Biotite	3.01
Oligoclase	17.06
Orthoclase	37.48
Quartz	30.24
Kaolin	7.25
Calcite	2.00
Residue	1.71
Total	99.86

The residue contains the extra water below 110°, traces of barium, strontium, manganese, etc., of which no account has been taken and which can have no important bearing on the above result. The oligoclase has been reckoned as Ab_3An_1, as the optical determinations, according to Michel Lévy's method, on Carlsbad and albite twins have shown it to have that ratio of soda to lime. This proves the orthoclase to be a soda orthoclase of the composition Ab_3Or_4, and the determination of the extinction angle on the face (010) of the phenocrysts made on cleavage material shows the angle of extinction to be 7° 30′ +, an extinction greater than that of pure orthoclase but not so great as many soda orthoclases show, which generally contain, however, more soda.

Contact.—At the contact with the shaly Cambrian beds, as is well seen on the saddle between Taylor Peak and the next peak north of it, the granite-porphyry magma has solidified as a dense, pinkish, felsitic looking rock without phenocrysts. It is, in fact, a typical felsite of a well-known type, and as such deserves no further mention. It gradually, as one proceeds inward toward the laccolith, changes to the granite-porphyry mentioned. Its lack of the larger phenocrysts of the granite-porphyry is very striking and is its most interesting feature, as it shows that these were not present in the magma at the time of its intrusion, but were formed later.

The exomorphic contact action is comparatively slight; the limy, shaly beds of the Cambrian are indurated for a few yards, and their cavities are coated with small crystals of grossular garnet and pyroxene; the metamorphism is similar to that described on page 540.

Mixes Baldy is composed of exactly the same type of rock, but the material shown in its outcrops and surface exposures is much more altered and decayed by weathering.

CARPENTER CREEK TYPE.

This is a variation of the foregoing type of granite-porphyry. It is called here the Carpenter Creek type, as it occurs locally well developed as an intrusion in the crystalline schists above Carpenter Creek. It is a rather light-gray rock, thickly spotted with pale-pink orthoclase phenocrysts 15 to 20 mm. long, which are generally Carlsbad twins. Between them are many small light-colored feldspar phenocrysts, which the microscope shows are oligoclase, and rather infrequent gray rounded phenocrysts of quartz from 6 to 8 mm. in diameter. The gray groundmass is speckled with minute black dots of a ferromagnesian mineral which under the microscope proves to be biotite. The study of the section adds nothing of special interest (excepting a character of the quartz phenocrysts, to be described later) beyond what has been mentioned in the foregoing type. There is a recurrence, however, of the biotite in the groundmass in little strips, shreds, etc. It differs from the preceding type chiefly in the hand specimen; that is, megascopically. The Wolf Butte type is remarkable for the abundant and large quartz phenocrysts. The feldspar phenocrysts are important, but not so important as in the Carpenter Creek type, while in the latter the quartz phenocrysts are not abundant. Both types have the micrograuitic groundmass.

To this type belongs the rock of the dike which cuts the limestone forming the bench north of Gold Run and near where it enters the main stream at Barker. The rock is of a brownish-gray color, and the feldspars and quartz phenocrysts are much smaller than in the preceding type. It contains hornblende, both as phenocrysts and in small prisms in the groundmass. Under this type come also the heavy intrusive sheets in the Cambrian beds, and just at their base, on the Sawmill Creek branch of Belt River. The road from Neihart to White Sulphur Springs passes up this creek, and its cuttings have exposed the igneous material. The rocks are light-colored porphyries with abundant phenocrysts of feldspar and less abundant ones of quartz. The same may be said of the dikes cutting Yogo Peak, and of the dike on the divide between Yogo Peak and Big Baldy Mountain, which occurs a little distance south of where the heavy talus slopes of Big Baldy Mountain reach the divide. The intruded sheet at the base of the Cambrian, which is exposed at the head of Dry Fork Belt Creek, on the spur running northward from Big Baldy Mountain, although somewhat deficient in quartz and inclining toward the syenite-porphyries, seems best placed here.

Structure of quartz phenocrysts.—In the granite-porphyries which have been previously described, especially in those from Wolf Butte and Snow Ceeek, which have large to good-sized phenocrysts of quartz, a curious structure has been observed. It is a multiple intricate twinning, seen with crossed nicols, by which the quartz of the phenocrysts looks almost exactly like a microcline, but the structure is much finer than in the generality of microclines; it has the same basket-work appearance. The difference in birefringence between the parts is less, however, than in microcline, and the phenomenon of twinning is faint, as in leucites. Not every phenocryst in a section shows this—only the larger ones. That the material is really quartz is shown by its form—that of the dihexagonal pyramid—the embayed character so well known in quartz phenocrysts, and its uniaxial positive character, all of which have been observed on crystals showing this twinned structure. I have been able to find no reference to anything similar in the literature, and can suggest nothing plausible to account for this curious structure.

YOGO PEAK TYPE.

This rock forms a great mass on the divide running east from Yogo Peak. It begins in the saddle just east of Yogo Peak proper, the syenite of the eastern part appearing to merge gradually into this type. It is feldspathic, light colored, dotted with small amphibole prisms; its chief characteristic, however, is that it is very porphyritic, with large equidimensional feldspar phenocrysts. These resist weathering better than the groundmass and project, giving the rock a rude resemblance to a conglomerate. In the saddle mentioned many of them have fallen out and form a rough gravel.

Microscopic characters.—In thin section the microscope discloses the following minerals: Apatite, zircon, titanite, hornblende, iron ore, biotite, orthoclase, oligoclase, and quartz.

The apatite and zircon are found in occasional small grains, usually embedded in biotite; titanite sometimes occurs in well-formed crystals, but is more likely to be in irregular masses, and it commonly accompanies the hornblende.

The hornblende occurs in irregular, shredded, broken crystals, which are often anhedral. Its angle of extinction is small, its pleochroism good, but not strong, with $\mathfrak{c}$=bluish green, $\mathfrak{b}$=olive green, $\mathfrak{a}$=greenish yellow, absorption $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$. It contains titanite, iron ore, and biotite as inclusions, and some crystals are hollow and contain pieces of quartz and feldspar of the groundmass.

The biotite is the usual dark-brown, strongly pleochroic variety found in granitic rocks. It is usually in good crystals. Its period of formation appears to follow the hornblende. The actual amount of both hornblende and biotite is comparatively small, and they are strictly accessory minerals, as biotite usually is in granitic rocks.

Following the biotite and hornblende in the order of crystallization comes the oligoclase. It is found in short, broad tablets inclining to columnar forms on the *a* axis, and sections across these are perfect squares; it is, therefore, quite idiomorphic. It ranges from 1 to 2 mm. in length, and is a rather abundant phenocryst. It is always twinned according to the albite law, often following that of the Carlsbad; a few pericline twins were seen. It varies in composition from Ab_4 An_1 to Ab_3 An_1; thus, a section oriented in the zone perpendicular to 010, and showing a negative bisectrix centered in the field, gives extinction angles of 0° for both sets of albite lamellæ; the section is zonal and the outer zone extinguishes at 5°; the equal illumination between the two is produced at a little over 40°, and we have here, following Michel Lévy's tables, an oligoclase with from 15 to 20 per cent An. The parallel extinction of numerous other sections in this zone confirms this determination.

By far the most abundant mineral is the orthoclase, which occurs in phenocrysts, from examples 2 or 3 mm. long, stout columnar on the *à* axis, and showing the forms *c* (001), *b* (010), *m* (110), and *x* ($\bar{1}01$) or *y* ($\bar{2}01$), down to individuals 1 mm. long and less perfect in form. The largest phenocrysts, while not abundant, are rather regularly sprinkled through the rock.

The determination of the mineral as orthoclase rests on the fact that in sections parallel to *b* (010) an obtuse positive bisectrix emerges and the plane of the optic axes lies at 8° from the trace of *c* (001) in the obtuse angle *β*. Sections perpendicular to the negative bisectrix show a rather large angle in air (and therefore not sanidine), and the extinction is rigidly parallel to the trace of *c* (001). The mineral is quite fresh and clear.

Quartz occurs only very rarely in such a manner that it may be said to rank as a phenocryst; it then occurs in irregular areas with projecting tongues and small fringes of attendant quartz with similar orientation.

The groundmass, compared with the total bulk of the phenocrysts, is rather small in amount; it occupies mostly the angular interspaces between the phenocrysts, is rather coarse, and has a microgranitoid structure; it is chiefly composed of quartz and alkali feldspar, with a very subordinate amount of oligoclase. The quartz grains are very likely to be disposed like beads around the largest feldspars.

Structure and classification.—The dominant character is given to this type by the great abundance of the phenocrysts, the small amount of groundmass, and the gradual passage of the phenocrysts by graduation in size into the groundmass. The structure is therefore really a transition between the hypidiomorphic structure of granular abyssal rocks and the typical porphyritic structures. A striking feature is the rounded granular, idiomorphic character of the quartz grains in the groundmass, which latter, indeed, has the aspect of a rather fine aplite.

In normal position this rock must stand between a typical granite-porphyry with characteristic quartz phenocrysts and abundant quartz in its groundmass and a syenite-porphyry devoid of quartz phenocrysts and with little to no quartz in the groundmass.

With respect to its feldspar constituents, the alkali one so plainly rules that the rock clearly belongs in the granite-syenite series; it does not, however, belong to the alkaline family, but to the one approaching the diorites. If Brögger's group of monzonites, that is orthoclase-plagioclase rocks standing between the alkali feldspar series and the soda-lime feldspar series, be taken into account, then the type just described stands midway between the alkaline series and the monzonites (adamellite).

Transition forms.—This type, by simple decrease of quartz and increase of other constituents, goes over locally into subvarieties which may be properly termed quartz-syenite-porphyries. One notices this first by the loss of quartz as a phenocryst and its entire restriction to the groundmass, by which it becomes very subordinate in amount. All the other components remain the same, and the gradational type needs no further mention. Though somewhat coarser grained, it is extremely similar to the type composing the great mass of Big Baldy Mountain, elsewhere described. For this reason no analysis of it has been made. It is the type which geologically borders the syenite of Yogo Peak proper.

BARKER TYPE.

The rock composing the great laccolith of Mount Barker is a granite-porphyry, but of different character from the typical one of the Wolf Butte and Mount Mix laccolithic masses. It is a grayish porphyry which appears rather granular, dotted thickly with feldspar phenocrysts from 5 to 10 mm. long and of tabular habit, with occasional scattered ones three to five times as large. These are unstriated and of orthoclase. The surface of the rock is well sprinkled with small, dull, black spots which are an altered ferromagnesian mineral. Quartz as a phenocryst is almost entirely wanting, and this is the most marked feature in contrast with the typical granite-porphyry of Wolf Butte.

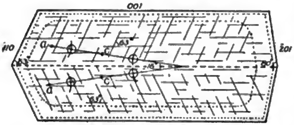


FIG. 74.—Manebach twin.

Under the microscrope the sections show phenocrysts of orthoclase and oligoclase of the composition approximately Ab_3An_1 lying in a quartz and alkali feldspar groundmass. There is a little iron ore, some fresh brown pleochroic biotite, and pseudomorphs, in part of chlorite and muscovite after biotite, in part of serpentine, iron ore, etc., after hornblende. In some sections the amphibole is fresh and of the usual columnar form and olive-green color of common hornblende. When it increases in amount, biotite diminishes, and vice versa. When most abundant, it is accompanied by occasional small, well-formed crystals of titanite.

The groundmass is an interesting feature. It is somewhat variable in its degree of granularity, but is always micropoikilitic, and in the type analyzed from the summit of the mountain it is rather coarse. When examined with a high power the small feldspar grains are seen lying embedded in fields of quartz, each of which forms one quartz crystal, while the feldspar has no orientation. There are a few clear areas of quartz which might almost be termed phenocrysts.

One of the large orthoclase phenocrysts in the sections is of interest as it chances to be a Manebach twin cut almost exactly parallel to the face 010, and it shows the relations exhibited in fig. 74. There are two lines of growth clearly seen revealed by a sharp line of tiny inclusions and by a slight but perceptible difference in optical properties, the outer shells extinguishing at perhaps half a degree to a degree greater angle than the main inner portion, indicating probably an increase in the albite molecule. That the albite molecule is present is indicated by the extinction angle of 8°, and this is confirmed by the analysis of the rock. It is interesting to notice that the mineral shows a good parting parallel to the prism, as indicated in the figure.

An analysis of the rock has been made by Dr. Hillebrand with the results here given:

Analysis of granite-porphyry from Mount Barker, Montana.

Constituent.	I.	II.
SiO_2	68.60	1.143
Al_2O_3	16.13	.156
Fe_2O_3	2.22	.013
FeO	.44	.006
MgO	.72	.018
CaO	1.36	.024
Na_2O	4.37	.070
K_2O	4.89	.052
H_2O − 110°	.20	.011
H_2O + 110°	.58	....
TiO_2	.32	.004
P_2O_5	.18	....
SO_3	Trace.	....
Cl	Trace.	....
MnO	Trace.	....
BaO	.27	....
SrO	.09	....
Total	100.37	....

I. Percentages.
II. Molecular proportions.

From this analysis we may reckon, using the molecular ratios given in the second column and taking into account the relations and kinds of minerals seen in the section, that the rock has approximately the following composition:

	Per cent.
Iron ore	1.4
Biotite	4.6
Oligoclase	25.6
Orthoclase	36.2
Quartz	25.2
Hornblende and alteration products	7.0
Total	100.0

This alteration material comprises the chlorite, serpentine, etc., and may be regarded as the residue; the figure given is not very accurate, but can not be far from the right amount. The oligoclase is reckoned as Ab_3An_1, as shown by the microscope; the orthoclase by this reckoning becomes, as an average, exactly Or_1Ab_1, and must therefore be mainly a soda orthoclase.

The peculiarity of this type of granite-porphyry lies in the fact that with so abundant quartz there is none appearing in definite phenocrysts; it is all in the groundmass. Here, however, it is so abundant as to condition the poikilitic structure, and in fact, at first sight, the hand specimen appears granular, much like an aplite. Study with the microscope shows us, however, that the grains are really quartz sponges filled with unoriented grains of orthoclase.

THUNDER MOUNTAIN.

The porphyry composing the great laccolith of Thunder Mountain also comes under the head of this Barker type. It is a light-colored rock, thickly dotted with numerous phenocrysts of feldspar, which occasionally attain large size, and with small black spots of hornblende or shining biotite. The rock appears quite fresh and unchanged; in the enormous exposures on the mountain side it occurs in large plates and rhomboidal blocks.

Under the microscope this type appears like the preceding; it consists of iron ore, apatite, biotite, hornblende, plagioclase, orthoclase, and quartz.

The biotite, of the usual brown pleochroic type, is quite idiomorphic and moderately abundant; the hornblende is the olive-green variety of common hornblende. It is in columnar crystals defined by the prism faces. A few resorptions and alterations to augite (?), iron ore, and biotite were seen; in these cases the biotite is on the outer boundary, where the magnesia of the hornblende has come in contact with the potash and alumina of the feldspar. The hornblende is more plentiful than the biotite. The plagioclase is variable; some of the phenocrysts are of andesine, some of basic oligoclase, some are zonally built; there is very little in the groundmass, and that appears to be oligoclase. It is not exactly easy, with these varying data, to determine what the

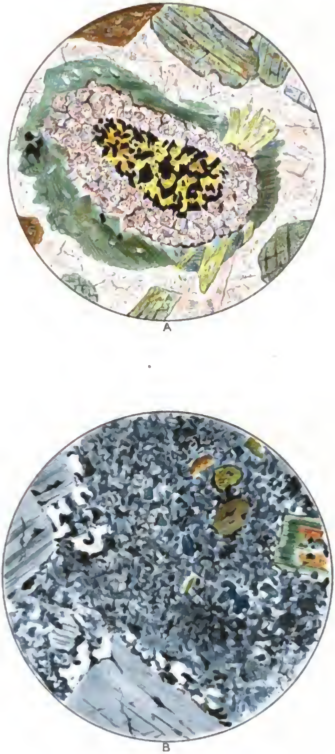
PLATE LXXIV.

PLATE LXXIV.

THIN SECTIONS OF OLIVINE AND GRANITE-PORPHYRY.

A, Resorbed olivine in shonkinite of Yogo Peak. The central core of yellow and black is the remnant of the olivine (now altered); around this is a band of light-brown enstatite granules, and outside of this another band of green biotite; the whole surrounded by white orthoclase, with one or two grains of green augite and brown biotite. Actual size of field, 2 mm. multiplied by 38, section seen in polarized light, uncrossed nicols.

B, Granite-porphyry of Thunder Mountain. Ferromagnesian minerals, green hornblende and brown biotite, seen with uncrossed nicols; magnetite dark blue. Orthoclase, plagioclase, and quartz seen with crossed nicols. The groundmass has a micropoikilitic structure. Actual size of field, 2 mm. multiplied by 38.



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THIN SECTIONS OF OLIVINE AND GRANITE-PORPHYRY average plagioclase is, for the purpose of calculating how much of the albite molecules shall be assigned to the anorthite and how much to the soda orthoclase. After careful study of the sections and estimation of all the data at hand, it is determined that it must be very close to an oligoclase Ab_2An_1; it certainly runs in some cases into andesine, and it may thus be that the weight of plagioclase as reckoned is too great, but probably not very much.

The orthoclase presents the same features as those described for the rock from Mount Barker; its extinction angle on 010 is 8° to 9°, which indicates the presence of soda, and the calculation of the analysis shows that it is Or_3Ab_2. Besides the usual Carlsbad twins, Manebach twins also occur, as shown in fig. 74. The orthoclase forms the largest phenocrysts, the plagioclase is likely to be relatively small.

The groundmass consists of alkali feldspar and quartz, with a little oligoclase. The structure is pronouncedly micropoikilitic, with quartz as the oriented cementing mineral; it is considerably coarser in grain than the Mount Barker variety, and the quartz sponges are much larger, but the effect is the same. An endeavor to show this groundmass with its poikilitic groups has been made in Pl. LXXIV, *B*.

As this rock appeared much fresher than that from Mount Barker, an analysis of it has been made by Dr. H. N. Stokes, of the United States Geological Survey, with the following results:

Analysis of granite-porphyry from Thunder Mountain, Montana.

Constituent.	I.	II.
SiO_2	67.44	1.124
Al_2O_3	15.78	.153
Fe_2O_3	1.58	.010
FeO	.85	.012
MgO	1.43	.035
CaO	2.38	.043
Na_2O	4.11	.066
K_2O	4.87	.052
H_2O — 110°	.32	.018
H_2O + 110°	.70	.039
TiO_2	.32	....
P_2O_5	.21	....
SO_3	Trace.	....
Cl	Trace.	....
MnO	Trace.	....
BaO	.24	....
SrO	.09	....
Total	100.32	....

I. Percentages.
II. Molecular proportions.

The correspondence in composition between this and the Barker rock is very close—they are rather low in silica, and in this respect approach the syenite-porphyries.

From the table of molecular ratios given in the second column, and aided by the study of the thin section, we may calculate the approximate mineral composition to be—

	Per cent.
Magnetite	2.4
Hornblende	3.5
Biotite	2.0
Oligoclase	28.9
Orthoclase	42.8
Quartz	20.4
Total	100.0

The above composition places this rock in the granite-porphyries, though the lack of quartz phenocrysts gives it a tendency toward the syenites. It also has a tendency toward the diorites, and clearly does not belong in the alkaline subdivision of the granite group, but at the head of the granito-dioritic family. Lindgren,[1] who has previously given a description, but no analysis, of this rock, called it a dacite, as its age was supposed to be post-Cretaceous and the prevaling method of classification at that time being based on the character of the feldspar phenocrysts, and as these are more numerous than those of orthoclase, it was naturally classified as a dacite. When, however, one has an analysis to calculate from, and the rock including the groundmass is considered as a whole, then it is seen that orthoclase predominates, as shown above.

If the lack of quartz phenocrysts be taken into account in the classification, such rocks as these might well be called granite-syenite-porphyries.

TIGER BUTTE.

The rock composing the laccolith of Tiger Butte is of this type; in the hand specimen it is scarcely to be distinguished from the Thunder Mountain rock; in thin section it is exactly like the Barker type, and needs no further mention.

BIG BALDY MOUNTAIN.

The rock composing the great laccolith of Big Baldy Mountain appears to belong in this group. Like those preceding, it is light colored, feldspathic, with numerous small phenocrysts of oligoclase, also some of orthoclase, with occasional large, well-formed idiomorphic crystals of orthoclase up to an inch or more long (15 to 25 mm.) which show the common forms *c* (001), *b* (010), *m* (110) and *y* ($\bar{2}01$); they are often Carlsbad twins. The groundmass is dotted with specks of ferromagnesian minerals which never attain large size.

The microscope shows in addition iron ore, titanite, apatite, hornblende, biotite, and quartz.

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[1] Tenth Census, Vol. XV, p. 722; Proc. California Acad. Nat. Sci., 2d series, Vol. III, p. 42.

The hornblende is a rather curious pale leather-brown variety, very slightly pleochroic, of very low birefringence and small extinction angle. The study of the plagioclase shows it to be a rather basic oligoclase of the average composition $Ab_2 An_1$. The orthoclase is not only a soda orthoclase, but is full of microperthite growths of albite, and its patchy, flamed, unhomogeneous character exhibits the considerable amount of soda present. The calculation of the analysis in fact shows the average of the alkali feldspars to be $Or_6 Ab_5$. The groundmass is of alkali feldspar and quartz, which is rather coarse and in a microgranitic structure, at times approaching to a micropoikilitic one. The analysis of the rock by Dr. W. F. Hillebrand gave the following results:

Analysis of porphyry from Big Baldy Mountain, Montana.

Constituent.	I.	II.
SiO_2	67.04	1.117
Al_2O_3	15.25	.148
Fe_2O_3	1.69	.011
FeO	1.13	.016
MgO	1.75	.043
CaO	2.17	.039
Na_2O	4.09	.066
K_2O	5.10	.054
$H_2O + 110°$	.51	.028
$H_2O - 110°$	.56	....
TiO_2	.20	....
P_2O_5	.21	....
MnO	.05	....
BaO	.33	....
SrO	.03	....
Total	100.11	....

I. Percentages.
II. Molecular proportions.

As in the former cases, by use of the molecular ratios in connection with the facts discovered in the thin section, we may calculate the approximate composition of the rock to be—

	Per cent.
Apatite, titanite, etc.	1.0
Magnetite	2.4
Biotite	3.2
Hornblende	4.8
Oligoclase	22.2
Orthoclase	47.0
Quartz	19.4
Total	100.0

This is very similar in composition to the rock of Thunder Mountain. As previously remarked, none of these rocks are to be considered typical granite-porphyries, since they lack quartz phenocrysts and the quartz present is only discovered under the microscope. They approach closely to the syenite-porphyries, as previously remarked, and might be termed granite-syenite-porphyries.

GRANITE-SYENITE-PORPHYRY.

Tillinghast laccolith.—What has been previously stated under the description of the granite-porphyry of Big Baldy Mountain, in regard to its transitional character, becomes still more evident in the case of several other occurrences. This is well illustrated in the porphyry composing the large laccolith just south of Thunder Mountain and lying between and drained by the heads of Tillinghast and Tenderfoot creeks.

It is a gray feldspathic porphyry, thickly spotted with small feldspar phenocrysts and small black dots of mica and hornblende. It lacks the large orthoclase phenocrysts which distinguish the previous types, and has also none of quartz.

In the section it appears that orthoclase and oligoclase are about equally divided in the number of phenocrysts. Hornblende is quite common, in well-formed prisms of the usual olive-green color; biotite is less abundant. These phenocrysts lie in a microgranitic groundmass of quartz and alkali feldspar of rather fine grain. It is noticeable that the quartz is quite idiomorphic, its sections furnishing little squares; in amount there is far less of it than in the preceding types, and the rock is therefore classed under the transition types.

Sage Creek Mountain.—Under the type previously described should be included the igneous rock of the laccolith at the head of Sage Creek. The road passing over the divide at the head of Bear Park and down Sage Creek through the limestone canyon, passes the edge of this laccolith and affords excellent fresh material. It is so similar to the rock just described that it needs no further mention.

Intrusive sheets.—Intrusive sheets of porphyry at the following localities may be placed under this type: In the Cambrian beds at the head of Sawmill Creek branch of Belt Creek, crossed by the road to White Sulphur Springs; in the Cambrian beds on the spur between Harrison and King creeks, where its exposure forms a mass on the ridge; in the Cambrian shales and Devonian beds on the northwest side of upper Dry Wolf Creek, where the successive sheets form a series of benches on the wooded hillsides.

There is some variation among these types. In some there is a tendency to a micropoikilitic structure in the groundmass, the amount of quartz being too small for a full expression of the structure; in others the feldspars of the groundmass tend to assume lath-shaped forms and produce a transition toward the orthophyres mentioned later. Nearly all of these sheets are greatly altered and decayed, the former ferromagnesian mineral being indicated by pseudomorphs or rusty spots. Some have biotite alone, others biotite and hornblende. The feldspar phenocrysts are usually small, considerable oligoclase is present, and the rocks show tendencies toward the diorite group. They are none of them of the alkaline series.

SYENITE-PORPHYRY.

In several localities in the Little Belt Mountains there are intruded sheets of a rock which is best classified as a syenite-porphyry. Although there are small differences in texture and appearance among the rocks from the different localities, such are of minor importance, and on the whole the different specimens resemble one another in a quite remarkable degree, so that one description will do for them all. In the hand specimen they are purplish or chocolate-colored rocks, dotted with numerous very small white feldspar phenocrysts, which are formless in shape, and with many phenocrysts of slender, dark, blackish-green columns of hornblende. The feldspars average about 2 mm. in diameter, the hornblende prisms 5 mm. in length.

The groundmass becomes granular under the lens, and its purplish tone suggests the keratophyres of several foreign regions. All the different localities furnish material more or less altered, and in all the rocks are rather dull and lusterless.

In thin section they are seen to be composed of phenocrysts of orthoclase and oligoclase, which are of the common habit seen in such porphyries, embedded in a groundmass of alkali feldspar with some quartz. Hornblende also occurs, of the usual olive-green pleochroic variety found in the syenitic rocks of the group rich in lime and magnesia. The structure of the groundmass is microgranitoid. The feldspars, which are often twinned as Carlsbads, are in short, broad forms and show sometimes a tendency toward a trachytoid structure, tending to throw the rocks into the orthophyre group. At all times this groundmass is rather fine in its granularity. The quartz in minute grains fills the interspaces in the groundmass, and it sometimes appears partly secondary in character. The feldspars are more or less turbid from the presence of kaolin, especially in the groundmass, and the hornblendes are in some places altered to calcite, chlorite, and perhaps serpentine, and there are some fine calcite particles scattered through the groundmass. A little biotite, often changed to chlorite, with iron ore, and apatite completes the list of minerals.

An analysis of the freshest of these rocks has been made by Dr. Hillebrand, with these results:

Analysis of syenite-porphyry from Little Belt Mountains, Montana.

Constituent.	I.	II.
SiO_2	62.58	1.043
Al_2O_3	16.42	.159
Fe_2O_3	2.46	.015
FeO	1.96	.027
MgO	1.84	.046
CaO	2.47	.044
Na_2O	4.57	.073
K_2O	3.91	.041
$H_2O+110°$	1.40	.077
$H_2O-110°$	.38	....
TiO_2	.40	....
P_2O_5	.33	....
CO_2	.77	.017
MnO	.08	....
BaO	.41	....
SrO	.10	....
Li_2O	Trace.	....
Total	100.08	....

I. Analysis of syenite-porphyry of rock from ridge between Big Baldy Mountain and Yogo Peak.
II. Molecular proportions.

The locality is on the ridge between Yogo Peak and Big Baldy Mountain. The rock is from an intrusive sheet whose exposure forms a cap on the ridge. The 1.78 per cent of water shows that the rock has suffered some alteration, and this is confirmed by a calculation of its mineral character, which gives approximately the following relations:

	Per cent.
Iron ore	3.5
Hornblende	8.4
Oligoclase	10.8
Orthoclase	52.7
Quartz	11.5
Kaolin	9.6
Calcite	1.7
Biotite, chlorite, apatite, etc	1.8
Total	100.0

The oligoclase is reckoned from the study of the section as Ab_4An_1, and from this the alkali feldspar or orthoclase averages a soda orthoclase Or_2Ab_3.

Other localities for these rocks besides the one just mentioned are the sheet, perhaps 100 feet in thickness, intruded in the Cambrian beds at the head of Belt Creek, about 6 miles or so above Neihart, forming some heavy outcrops and talus slides close by the stream, and also in the Cambrian beds on the Sawmill Creek branch of Belt Creek below the heavy sheet of granite-porphyry at the winding of the road. This sheet is about 10 feet in thickness. Several sheets of this rock are also exposed on the crests of the spurs leading down from the ridge between Yogo Peak and Big Baldy Mountain into the extreme head of Belt Creek; the rocks are sometimes quite fine-grained and dense, with platy parting, and in that case of gray color. Although somewhat different, on account of the finer grain, they are best placed under this type.

King Creek intrusives.—At the head of Weatherwax and King creeks there occur, intruded as sheets in the Cambrian beds, a number of igneous rocks of porphyritic habit, which are best included under the syenite-porphyries. They are light-colored, feldspathic rocks, which generally have a pinkish tone from the iron hydroxide scattered through them and resulting from the decay of some former iron-bearing component. All of these rocks are greatly altered and kaolinized, and in part mineralized, so that they have been more or less actively prospected. They usually carry altered phenocrysts of orthoclase and plagioclase in a feldspathic groundmass. They are too greatly altered to afford any satisfactory material for petrographic study.

DIORITE-PORPHYRY.

Between the granite-porphyries without phenocrysts of quartz but with abundant quartz in the groundmass, which pass into syenite-porphyries whose quartz is merely accessory, and the series of the diorite-porphyries, there are in this district many transitional rocks. Some of these transitions have been already described. They occur chiefly in the sheets and laccoliths. The diorite series of this group of porphyries will now be described. The most typical is the rock composing the laccolith of Steamboat Mountain.

STEAMBOAT MOUNTAIN TYPE.

The great laccolith of Steamboat Mountain which has been injected into the Cambrian shales has domed them up, along with the heavy beds of the Carboniferous limestones, and now lies in considerable part exposed by erosion. The igneous rock has a thin platy parting, and the plates lie piled conformable to the laccolithic surface. This is unusual in laccoliths of acid feldspathic rock possessing a platy parting of the material near the laccolithic boundary, since generally the plates have a radial deposition and stand on end, perpendicular to the domed surface. The rock is of a dark-gray color, quite fine grained, thickly spotted with small, white, formless feldspar phenocrysts. In addition, the groundmass glistens with the reflection of light from numerous cleavages of tiny black biotites which minutely speckle its gray surface. The rock appears granular to the eye, but its grains are too fine to recognize.

Under the microscope the minerals seen are phenocrysts of hornblende, biotite, and plagioclase in a groundmass of plagioclase, alkali feldspar, and quartz. Scattered grains of iron ore and a trace of titanite are present.

The hornblende is quite idiomorphic in columnar crystals, having the color and pleochroism of ordinary olive-green hornblende. In addition there are smaller shreds and grains; a few lighter-colored grains may be of augite.

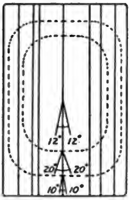


Fig. 75.—Zoned plagioclase (andesine-labradorite-andesine) in diorite-porphyry of Steamboat Mountain.

The biotite also is somewhat variable in size, the larger crystals being well formed and mixed with smaller pieces. It is a light-brown pleochroic type, and is older than the hornblende, for the latter often incloses it.

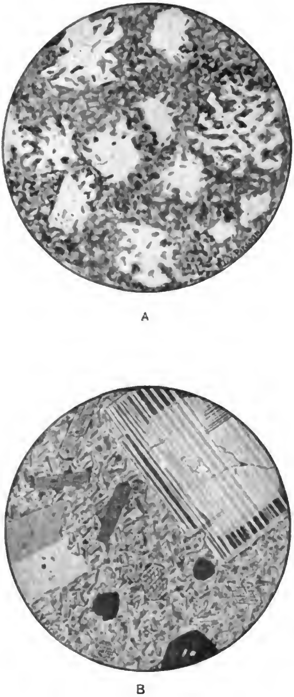
All of the feldspar phenocrysts appear to be of plagioclase. Their composition is somewhat variable, running through the oligoclases into the andesines, and even more basic varieties occur. Thus, as shown in fig. 75, a crystal oriented in the zone perpendicular to 010 shows a zonal banding. The albite twins of the core extinguish at 12°, the zonal band at 20°, and the outer rim at 12°. Equal illumination takes place at +36, and the core shows a nearly centered in the field. At 44° the albite twinning also disappears. Hence the core is cut at 65°+ from zero, and contains 30 per cent of anorthite and is an andesine; the zonal band contains 38 per cent of anorthite and is an acid labradorite; the rim is also an andesine.

The composition of the small plagioclases in the groundmass is more acid than this, and while it is difficult to decide what the average plagioclase is, it is believed to be approximately about Ab_2An_1; that is, a basic oligoclase.

In company with this plagioclase a considerable proportion of orthoclase and quartz is also present, entirely, so far as can be told, in the groundmass.

The structure of the groundmass is microgranitoid, and the plagioclase has a tendency to a short lath form, which gives this groundmass a perceptible microlitic character. In it lie, irregularly sprinkled, the numerous small phenocrysts. The character of the rock and the structure of the groundmass are illustrated in the microdrawing shown in Pl. LXXV, *B*.

The chemical composition is seen from the following analysis by Dr. W. F. Hillebrand:



A. MICRO-DRAWING OF RHYOLITE-PORPHYRY
B. MICRO-DRAWING OF DIORITE-PORPHYRY OF STEAMBOAT MOUNTAIN

QUARTZ-DIORITE-PORPHYRY.

This occurs at several localities, each of which is marked by some small local peculiarity. The phenocrysts of feldspar vary from oligoclase to andesine, and they are generally rather small and well formed; there are sometimes present a few rare, scattered, large orthoclase phenocrysts. The dark-colored minerals are hornblende and biotite, both of which are present, sometimes fresh, sometimes altered, and generally of small size and inconspicuous, except under the microscope. The groundmass is made up of quartz and feldspar in about equal proportion, sometimes in a micrographitic structure, sometimes in a micropoikilitic one. The proportion of orthoclase to plagioclase in this groundmass is generally about one to one. The quartz phenocrysts are not abundant, nor are they large or well formed.

Examples of these rocks are found in the intrusive sheets in the Carboniferous beds at the head of Dry Wolf Creek; in the spurs running southeast from Mount Taylor; in the dike cutting the Cambrian rocks exposed in the stream at Barker and opposite the railroad station; and in a sheet, about 15 feet in thickness, which is exposed in the Cambrian shales on upper Dry Wolf Creek, in one of the spurs leading down from Big Baldy Mountain. At the latter locality the porphyry sheet was cut by a much-altered minette dike, with trend southward toward Yogo Peak.

A variation of this type is found in the porphyry composing the large flat area on the ridge east of Yogo Peak and east of the type described on page 502 as the Yogo granite-porphyry; it is between the head of Elk Gulch and the fork of Dry Wolf Creek, and is south of Storr Peak. The rock in the hand specimen is similar to the Yogo granite-porphyry, and has the same minerals and structure under the microscope, and the same beading of the feldspars with little quartz grains. The orthoclase of the granite-porphyry has given way, however, to oligoclase, which is the predominant feldspar, and the type has become, in fact, a granite-diorite-porphyry, as there is still much orthoclase in the groundmass.

SYENITE-DIORITE-PORPHYRY.

Just as transition forms occur between the granite- and syenite-porphyries and the granite- and diorite-porphyries, there are also those between the syenite- and diorite-porphyries. Excellent examples of this type compose that part of the great intrusive mass which runs eastward from Yogo Peak and which composes the slopes of Sheep Mountain and the masses east of it. An example from the talus slopes which border Bear Park at the head of Bear Creek above Yogo is selected for description.

In the hand specimen the type closely resembles the other porphyries described, especially those forming the laccoliths in great part. In a very fine granular groundmass of very pale chocolate color lie, thickly crowded, small white phenocrysts of feldspar, which are only moderately well-formed crystals; the groundmass is further spotted by numerous small black specks of shining biotite and small slender hornblendes. There are numerous tiny cavities of miarolitic character.

In the section there are seen phenocrysts of soda orthoclase of homogeneous aspect, of plagioclase varying from andesine to oligoclase and about equal in size and number with the orthoclase, idiomorphic biotite and green hornblende in a microgranitoid groundmass of quartz and alkali feldspar, with some oligoclase, which is not so common, apparently, as the orthoclase. The rock is so similar to others which have been previously described that no further details are necessary.

An analysis of this rock has been made by Dr. H. N. Stokes, with the following results:

Analysis of diorite-syenite-porphyry from Bear Park, Montana.

Constituent.	I.	II.
SiO_2	64.95	1.082
Al_2O_3	15.44	.150
Fe_2O_3	2.02	.013
FeO	1.60	.022
MgO	2.65	.066
CaO	3.07	.055
Na_2O	4.25	.068
K_2O	3.87	.041
$H_2O + 110°$	.85	.047
$H_2O - 110°$	.26	
TiO_2	.39	
P_2O_5	.25	
SO_3	.02	
Cl	.04	
MnO	Trace.	
BaO	.35	
SrO	.10	
Total	100.11	

I. Analysis of diorite-syenite- (monzonite-) porphyry, talus slope west side of Bear Park.

II. Molecular proportions.

Wolf Butte laccolith exposed on the saddle between Taylor Mountain and the next peak north.

Type No. 2.—In this the groundmass is of the same microgranitoid character described in type No. 1, but there are numerous phenocrysts of feldspar and quartz. The feldspar phenocrysts are generally orthoclase, with smaller ones of oligoclase or andesine. Usually they are more numerous than those of quartz, but in one case, Neihart Mountain, the reverse is true. These are the types of rhyolite-porphyry (quartz-porphyry) which tend to transitions into the granite-porphyries.

The size of grain of the groundmass is variable; in one case (Neihart Mountain) it is exceedingly fine and suggests a possible devitrified glass; others are much coarser. The dark components are rare, and are mostly chloritized biotites. None of the rocks are very fresh; all are somewhat filled with calcite, sericite, or kaolin. In one phase (Ricard Peak) most of the feldspar and quartz phenocrysts are quite small, only to be seen with the lens, and there are many slender columnar hornblendes of the common green variety, also brown biotite foils, which megascopically spot the rock surface with slender black lines. Another phase of this type (intrusive sheets on Dry Fork Belt Creek above Barker) is a transition into the granite-syenite-porphyries, described under the laccolith rocks. The phenocrysts of feldspar are more numerous, those of quartz less common; the feldspar of the groundmass has a very slight but distinct tendency toward idiomorphism, giving a suggestion of the trachytoid structure of syenite-porphyries; the quartz diminishes in amount and tends to fill angular interspaces; the dark minerals are biotite and hornblende. The rocks are somewhat altered. Megascopically they exhibit many small phenocrysts of feldspar and hornblende and very few of quartz. They appear very much like the chocolate-colored syenite-porphyry previously described, and are, in fact, a transition between it and a typical rhyolite-(quartz-)porphyry.

Type No. 3.—In the third and last type the groundmass is micropoikilitic, a mixture of orthoclase and quartz, with the latter oriented into spongy masses inclosing the feldspar. At times there are distinct transitions from these impure quartz sponges into regular clear quartz phenocrysts; the quartz, in crystallizing, has excluded more of the feldspar material and tended to become more homogenous. A drawing of this phase of the micropoikilitic groundmass is shown on Pl. LXXV, *A*, from the contact facies of Mount Clendennin, above the Tiger mine. The phenocrysts in this type are usually rare, and are of the character described above for the other types. Slender columns of hornblende are numerous in the Clendennin rock just mentioned.

Chemical composition.—The chemical composition of rocks of this class is so simple and well known that it usually offers little of general interest. In the present series, moreover, the types are more or less altered, in many cases mineralized, and the material not well suited for analysis. As a control, however, upon the petrographic work, and to ascertain that these types present nothing unusual from a chemical point of view, an analysis was made of the rock forming an intrusive sheet on the divide just west of Yogo Peak, whose felsitic character has been previously mentioned. The analysis is by Dr. W. F. Hillebrand.

Analysis of rhyolite- (quartz-) porphyry from near Yogo Peak, Montana.

Constituent.	I.	II.
SiO_2	73.12	1.218
Al_2O_3	14.27	.138
Fe_2O_3	.51	.003
FeO	.26	.003
MgO	.24	.006
CaO	1.10	.020
Na_2O	3.43	.055
K_2O	4.90	.052
$H_2O + 110°$	.73	.040
$H_2O - 110°$	.68	....
TiO_2	.08	....
P_2O_5	.03	....
CO_2	.77	.017
MnO	.06	....
BaO	Trace.	....
SrO	Trace.	....
Li_2O	Trace.	....
Total	100.18	....

I. Analysis of rock from divide west of Yogo Peak.
II. Molecular proportions.

The water and carbonic acid prove what the microscope has shown, that considerable alteration has taken place. The analysis is easily calculated into the mineral composition—

	Per cent.	
Iron ore	.8	
Muscovite	11.3	
Anorthite	.8	
Albite	29.4	51.8 $Or_{[illegible]}Ab_{[illegible]}$
Orthoclase	21.6	
Quartz	33.6	
Calcite	1.7	
Chlorite	.8	
Total	100.0	

Localities.—The following list gives the more important localities in which the porphyries just described are known to occur:

Ridge between Yogo Peak and Big Baldy Mountain; analyzed.

Head of Dry Wolf Creek; intrusive sheets at base and top of Big Baldy Mountain spurs.

Contact facies of Mount Lupus, Mount Taylor saddle.

Contact facies of Mount Clendennin, above Tiger mine.

Intrusive in limestones, extreme head of Dry Fork Belt Creek.

Intrusive sheets, Dry Fork Belt Creek a mile or two above Barker, chocolate colored.

Intrusive (laccolith), head of Otter Creek.

Intrusive forming hill on Running Wolf Creek below Woodhurst.

Masses of Ricard Peak.

Intrusive mass forming lowest north spur of Ricard Peak.

Localities on Neihart Mountain and on slopes of Snow Creek Valley.

TRACHYTE (BOSTONITE).

On the upper main head of Dry Fork Belt Creek there occurs, intruded in the Cambrian, a mass of igneous rock which, so far as the exposures warrant supposition, appears to be an intrusive sheet. It is near the boundary of the Cambrian, and above the locality, along the creek, there are open parks cut in Cambrian shale; the mass forms a wooded bench which yields a considerable talus along the stream.

The rock is of a light-brownish color, rather porous in texture (from numerous small miarolitic or steam cavities), coated with limonite, has a rough, trachytic feel, and is rather dense. The phenocrysts are entirely inconspicuous and consist of numerous very small, thin, tabular, sanidine-like feldspars, and others which are soft, lusterless, and kaolinized. Ferromagnesian minerals are almost entirely wanting; occasional rusty specks may be the remains of former ones.

In thin section the rock is found to consist almost entirely of orthoclase, with a very little quartz. The phenocrysts are homogeneous in structure, untwinned, and show none of the microperthite, soda-microcline, or moiré structures so common in this class of rocks. In sections perpendicular to $\mathfrak{a}$ the optic angle is small, the bars barely passing out of the field of the No. 9 objective of Fuess, i. e., 2E is in the neighborhood of 50°.

The small feldspars of the groundmass are in thin plates tabular on 010; they are extremely apt to be grouped together parallel to this face, so that at times they either actually form repeated Carlsbad twins or appear to do so, or are slightly divergent from one another. As these groups are cut at different angles by the section, the feldspars appear in rectangular laths in parallel positions or in broader formless plates. There is no sign of any albite twinning to be seen among them, and in all cases where they form rectangular sections with sharp clean edges without neighboring overlaps, which shows that the plate of feldspar (and therefore 010) is perpendicular to the section, they extinguish rigidly parallel, as a monoclinic feldspar should.

Practically the entire mass of the rock is made up of these plates of alkali feldspar, packed as closely together as is possible. The angular interspaces, which, so closely are they joined, are always minute, are usually filled with a small amount of quartz; sometimes they are empty, giving rise to minute miarolitic cavities. The structure of the rock is thus really the panidiomorphic of Rosenbusch, in the sense that the constituents have to a greater or less degree their own form; it is not of course the sugar granular structure of the aplites. Rosenbusch[1] includes all of the aplitic rocks in one group of his dike rocks, mentioning the panidiomorphic structure as being characteristic of the group. Brögger[2] has later suggested their division into two groups, the aplitic, with sugar granular structure, and the bostonitic, with trachytoid structure. This latter is the structure, in a very high degree, of the rock just described, and in rock classifications, where the mode of geologic occurrence is strongly taken into account, the rock is a typical bostonite; a more general term for it is trachyte.

The rock does not appear fresh enough to warrant a careful analysis, but since pure potash rocks are almost unknown, it seems clear that the alkali feldspar, its almost sole constituent, must be a soda orthoclase.

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[1] Mass. Gesteine, 3d ed., 1895–96, p. 388.

[2] Eruptivgesteine Kristianiagebietes; III, Ganggefolge des Laurdalits, 1898, p. 211.

CHAPTER IV.

THE LAMPROPHYRES AND THE EFFUSIVE ROCKS.

THE LAMPROPHYRES.

MINETTE.

Minette, which has been considered a rather rare rock in America, is frequently found in the Little Belt Mountains, and usually in the form of sheets intruded into the thinly bedded horizons of the Cambrian and Carboniferous. Its occurrence in dikes is much more uncommon, though a series of dikes occur at the head of Dry Wolf Creek which are closely related to these minettes. In a number of cases, however, dikes of minette are found in connection with the sheets, being, in fact, the feeding canals to them.

According as the minette is found in the very thin or in the thicker sheets it has a markedly different appearance in the hand specimen. In the thicker sheets it has, when fresh, a dark-gray color, and it is easily seen by the eye alone to be distinctly crystalline, and in certain cases it approaches the condition of a fine-grained granular rock. Occasional large biotites, quite idiomorphic and about 2 or 3 mm. across, are found playing the rôle of phenocrysts. In these coarser varieties the groundmass is easily differentiated into a white feldspathic component, in which lie innumerable small leaves of biotite, while smaller grains of a greenish pyroxene can be seen with the lens. This type of rock has a dull, hackly fracture. It occurs more abundantly among the sheets intruded in the Cambrian shales and limestones at the head of Sheep Creek.

The work done on the White Sulphur Springs and Neihart road, which follows Sheep Creek to the divide and crosses the strike of the beds and the intruded sheets, has exposed in a number of places material which is quite fresh, especially in one locality. The rock as here seen was the least altered of any obtained, and for a rock of this family was remarkably fresh, as disclosed not only by the study of the section but also by the analysis given later.

In the thinner sheets and in the few dikes in which this rock occurs it has a quite different appearance. It is very dark stone gray, almost black, of a very fine, dense grain, with a distinct conchoidal fracture. It has, in fact, a pronounced basaltic appearance and merits well the field term "mica trap," applied by the older geologists to this class of rocks. Occasional phenocrysts of biotite are seen in the rocks, and they are often speckled by small spots of white, which are mostly due to altered and calcitized augite crystals and included fragments of calcite.

MICROSCOPIC PETROGRAPHY OF THE MINETTE.

While the greater number of the occurrences of this rock are so greatly altered by weathering that no satisfactory results could be gained by

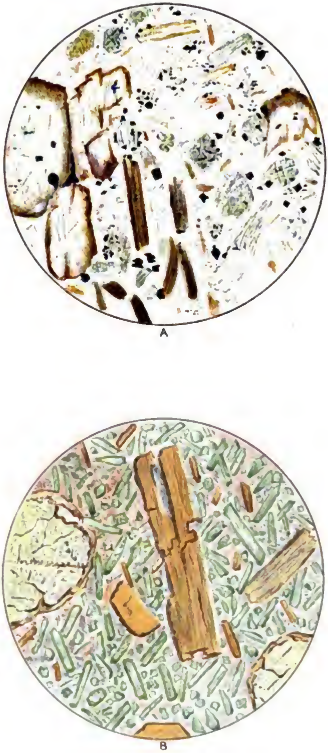
PLATE LXXVI.

PLATE LXXVI.

THIN SECTIONS OF LAMPROPHYRES.

A. Minette from the sheets and dikes at the head of Sheep Creek. Brown biotite, green augite, and black iron ore, in a mixture of white orthoclase and plagioclase. Seen in natural light; actual size of field 2 mm. multiplied by 38.

B. Analcite-basalt from dike cutting Bandbox Mountain. Olivine (yellow), biotite (brown), and pyroxene (green), lying in an isotropic pale-brown groundmass of analcite. Natural light; actual size of field 2 mm. multiplied by 38.



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THIN SECTIONS OF BASIC DIKE ROCKS, LITTLE BELT MOUNTAINS an examination of them, about two dozen were in a sufficiently good state of preservation to furnish fair material for study in thin section, and of these about one-third were practically unaltered. These show that the ordinary minerals of a typical minette are present—iron ore, apatite, biotite, augite, orthoclase, plagioclase—and in the altered varieties several decomposition products, which are, indeed, not wholly wanting in the very freshest examples.

Iron ore and apatite.—These present their usual characters. The ore grains are, as a rule, rather small, averaging about 0.03 mm. They are at times clustered bead-like along the edges of the augites in such a manner as distinctly to suggest a pushing and exclusion of the already formed magnetite grains by the growing and expanding augite. In a few instances quite large crystals of apatite were noted rising almots to the dignity of phenocrysts.

Biotite.—This has the typical micro character found in minettes. In the interior of the crystal the color is a brownish ocher-yellow, bordered by a mantle of deep brown, best seen in basal plates (see Pl. LXXVI, *A*), while in sections perpendicular to the cleavage the pleochroism is very strong, varying between pale yellow and deep brown. The larger phenocrysts are sometimes embayed, and the edges of the embayment are bordered by hexagonal boundaries. Sometimes the larger crystals are made up of smaller ones in parallel position. The great majority of the sections do not give an opening of the axial cross sufficient to tell whether the mica is a meroxene or an anomite, but in one case a distinct opening showed the trace of the axial plane perpendicular to one side of the hexagon; in this case the biotite is an anomite. In some cases the larger crystals exhibit a bending and deformation through stress, showing that they had crystallized out in the magna before it had attained its final resting place. In a few cases it is seen that the biotites have suffered magmatic resorption and are partially converted into opacite.

Augite.—This is a pale-greenish diopside. It rarely occurs in clear, well-formed, and distinct crystals. It is far more likely to be present in irregular masses and in collections of rounded grains with similar orientation or in small anhedrons. Compared with the biotite, it also varies considerably in amount and in relative quantity. In some cases it is scarcely present, in others it increases until it equals the biotite, and in a few dikes it preponderates, giving transition forms into lamprophyric rocks, to be described later. In a few of the coarser-grained minettes, where the augite is more idiomorphic, it frequently appears with secondary tufts of a finely fibrous hornblende attached to the basal plane. Both minerals have the vertical axis in common. This hornblende is a rich green in color and strongly pleochroic. Its angle of extinction is extremely small. Since its extension is optically positive and its pleochroism is in tones of green, it can not belong to the soda-iron group. In composition it differs from the very similar tufted groups described by Cross[1] as secondary on augite.

From its method of occurrence it is inferred that the augite occurs at times in two generations, though by far the greater part, like the biotite, belongs to the second.

Feldspar.—This is, of course, chiefly orthoclase, or at least an unstriated alkali feldspar. In the finer-grained varieties in the dikes and thinner sheets it has a lath-like form, giving a trachytoid appearance to the groundmass. In the coarser-grained types found in the thick sheets the orthoclase occurs in shapeless masses, which at times have a tendency to run into broad plates, inclosing the micas and other ferromagnesian minerals in a poikilitic manner. It is usually more or less clouded by incipient kaolinization, even in the freshest types, and in those in which decay is far advanced it is greatly altered.

Associated with this orthoclase there is a variable quantity of plagioclase. It has a strongly zonal formation and runs from interior cores of plagioclase as basic as labradorite down to albite on the outer borders. At times such individuals have an exterior mantle of orthoclase surrounding them, and it is to be suspected that as the inner shells pass into albite on the exterior, this in turn is succeeded by anorthoclase or soda-rich orthoclases, the orientation of the whole being preserved by this succession. In some of the smaller sheets the plagioclase does not become so basic as labradorite, and in these cases there is also less of it. The relative proportion, indeed, of orthoclase and plagioclase is quite variable, not only in the different occurrences compared with one another, but even in the same rock mass. While in all cases orthoclase is strongly the predominant feldspar, yet in certain cases local enrichments of plagioclase are found to such an extent that the rock assumes a kersantite facies. Here it is that the plagioclase assumes its most basic form. In general the plagioclase is fresher and much more limpid than the orthoclase.

Secondary minerals.—These are present in direct proportion to the amount of alteration the rock has suffered. The biotite changes into chlorite, the augite into limonite and masses of carbonates, while, as previously mentioned, the feldspars are changed into kaolin and allied products.

Structure.—The type of structure varies somewhat according to the mode of occurrence. In the dikes and thin sheets the lath-like form of the feldspar gives a somewhat trachytoid type of structure, very similar to that of the minettes so common in eastern Germany, but this type changes in the thicker sheets to one much more granitoid or hypidiomorphic in its character. This is caused by the gradual thickening and loss of definite form of the feldspar, which assumes the character of that seen in granites. It should, indeed, be stated that in some of the very thickest of the sheets the growing coarseness of the grain of these minettes, the absence of phenocrysts, and the structure described above, cause them to assume facies which are clearly transition forms into the mica-syenites, or, since rocks so basic as these and with so great an abundance of ferromagnesian minerals can scarcely be termed syenites with propriety, into rock types of which perhaps the durbachite of Sauer[1] is at present the only type which has been distinctly recognized and differentiated from the syenite group.

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[1] Am. Jour. Sci., 3d series, Vol. XXXIX, 1890, p. 359.

A figure of one of these minettes is given on Pl. LXXVI, *A*.

Chemical composition.—The chemical composition of these minettes is shown by an analysis of the very fresh and rather coarse-grained type (No. 274) taken from material brought out in the road-cut on upper Sheep Creek. The analysis is by Dr. W. F. Hillebrand and is given in Column I in the table below. This shows the composition to be that of a normal lamprophyre with low silica, moderate alumina and alkalies, with high iron, lime, and magnesia. The amount of carbonic acid is low for a rock of this class, and proves it to be fairly fresh. The water is no more than must be expected in a rock of this group, it being nearly impossible to obtain absolutely fresh material. Part of it probably goes with the biotite. For the sake of comparison, analyses of two other augite minettes from well-known and typical occurrences are given, and it will be seen that on the whole the agreement is very satisfactory. It agrees also fairly well with the durbachite of Sauer except in the potash and ferric iron, and we may conclude that the durbachite contains a larger amount of biotite.

Analyses of minettes.

Constituent.	I.	II.	III.	IV.
SiO_2	52.26	52.70	51.15	51.05
TiO_2	.58	1.71	(?)	1.76
Al_2O_3	13.96	15.07	15.91	14.49
Cr_2O_3	Trace.	....	....	....
Fe_2O_3	2.76	8.41	4.63	4.16
FeO	4.45	(?)	3.72	4.37
MnO	.14	....	....	....
MgO	8.21	7.23	4.14	8.16
BaO	.23	....	....	....
SrO	.05	....	....	....
CaO	7.06	5.33	7.68	5.11
Na_2O	2.80	3.12	1.92	1.85
K_2O	3.87	4.81	5.97	7.25
Li_2O	Trace.	....	....	....
$H_2O - 110°$	1.53	2.38	2.75	1.05
$H_2O + 110°$	1.34			
P_2O_5	.52	Trace.	(?)	.70
CO_2	.49	Trace.	2.12	....
Total	100.25	100.76	99.99	99.94

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[1] Mitteilungen d. Bad. Geol. Landesanstalt, II, 1892, p. 247.

I. Augite-minette (No. 274); Sheep Creek, Little Belt Mountains, Montana. W. F. Hillebrand, analyst.

II. Augite-minette; Weiler bei Weissenburg, Alsace. Linck: Abh. z. Geol. Specialkarte v. Elsass Löth., Bd. III, 1884, p. 55. G. Linck, analyst.

III. Augite-minette; Leonhardskopf bie Flockenbach. Roth, Tab., 1879, XXVI.

IV. Durbachite; Durbach, Schwartzwald. Sauer: Mitt. Baden Geol. Landesanst., Vol. II, p. 258.

Variolitic facies of minette.—In the compacter varieties of this rock occurring in the thinner intrusive sheets and in the dikes a variolitic facies at the saalband is not uncommon. Megascopically, in such cases the freshly fractured surface is seen to be thickly spotted by circular masses averaging from 2 to 5 mm. in diameter. They are of a pale-gray color, while the matrix in which they lie is a dull brown with greenish tinge. The difference in color is so pronounced that the rock has a strongly mottled character that at once arrests attention. Their number is very great; they are rarely separated by more than their own diameter, and in places are so thickly crowded that they touch one another, or even intersect in groups. They are more compact and coherent than the matrix, which on a fracture tends to break away from them, giving a gnarly, knotted appearance to the break. On a weathered surface the rock has a pale-brown color, and the matrix weathering faster than the spheres, leaves them projecting. The rock surface has thus a pronounced warty appearance, and it rudely resembles the perlitic development of acid glasses. On the other hand, the fractured surface recalls certain rhyolites with a spherulitic development. Its appearance is shown in Pl. LXXIII, *B*.

Examined with a lens, the varioles, as we shall call the globular bodies, are seen to be composed of a gray feldspathic mass flecked by tiny dark spots from which one catches the occasional reflection of a mica cleavage. As we approach the outer border of the variole the gray color changes within a narrow zone to pure white. Thus the variole is encircled by a mantle, which, on a fresh fracture, is easily seen by the naked eye as a white ring surrounding it. On close inspection with the lens, however, it may be seen that the border zone is not wholly composed of feldspar, but that it is traversed by many very narrow hair-like lines of black, which sometimes have a radial direction and sometimes not. These are the edges of very thin, small tables of biotite, commonly arranged so that the tabular face is either radially or tangentially disposed with respect to the spherical mass.

Under the lens the matrix in which the varioles lie is found to be extremely rich in biotite, compared with the varioles. While the grain is dense, the mica tablets can be easily seen. The boundary of the variole against the matrix is not a perfectly geometric one, but is rather wavy and irregular, though the boundary between the two colors is perfectly sharp. It is because of the greater richness of the matrix in biotite, which cleaves so readily, that the varioles may be separated out from it, and from its easy crumbling and decay that they are left projecting like warts from a weathered surface.

The characters described above become less and less noticeable as a greater distance from the saalband is reached, until eventually the rock attains its normal character. In the most developed case we have seen, the breadth of the variolitic band is about 6 inches, so that hand specimens can be made showing the varioles on all faces.

Microscopic characters of variolite.—Under the microscope the usual minerals of the minette are seen—iron ore, augite, biotite, and feldspar. In plain light the appearance of the section at first glance is similar to that of an ordinary fine-grained minette; the iron ore is in fairly good crystal form; the small stout prisms of augite are quite idiomorphic, and these, with the biotite, appear to be scattered irregularly through the section. It is noticeable that the biotite is in very thin leaves, which, when standing perpendicular to the section, show as very slender pleochroic rods. In certain places it is seen to be locally abundant. It is quite surprising how the strongly marked individuality of the varioles, which is so characteristic a feature megascopically, practically disappears in thin section, giving way to an appearance of uniformity. The thinner the section the more pronounced this becomes.

Between crossed nicols the study of the feldspar areas, which in white light are of a very pale ocher color and appear slightly kaolinized, shows that they are not made up of a single feldspar individual, but that they are composed of bundles of fibers arranged in plumose or fan like forms, across which the brush of an interference cross waves as the section is revolved. They are formed, in fact, of spherulitic growths of orthoclase, and the sensitive tint, showing that the fibers are extended in an optically negative direction, indicates that the development of the feldspar is, as usual, parallel to the clino-axis. The study of the development and arrangement of these growths shows that they start from some common center, such as a group of augites or of iron ore, and spread radially in all directions until interrupted by the interposition of the mass of some of the ferromagnesian minerals. Then from these they again start, preserving approximately the general radial direction, until finally the outer boundary of the variole is reached, where they meet spherulitic growths coming in the opposite direction, and the varioles intersect or terminate at the interspaces. The whole arrangement is similar to a great quantity of brushes placed radially in rudely concentric circles around some common point and mixed without arrangement with the ferromagnesian minerals. The mica, however, shows a tendency to arrange itself so that the basal plane is also radially extended.

The cusp-shaped and annular interspaces between the varioles, which appear so plainly in the hand specimen, are seen by study of the section to be local enrichments of biotite tablets, which are generally arranged tangentially to the spherulitic growths and cemented together by deep-brown glass. The study of these interspaces has not been as satisfactory as could be desired, owing to the difficulty which has been found in preparing thin sections. The varioles are much harder and resistant, and in grinding the crumbly brown material disappears long before the varioles are sufficiently thin. We have had to study it, therefore, in rather thick section, from which the above characters have been made out.

From what has been stated above, it seems evident that the varioles are spherulites of feldspar quite comparable to the spherulitic growths so characteristic of acid glasses. They differ, however, from the majority of these in that the spherulitic growth has been interrupted by the presence of augite and iron ore and has then repeated itself, thus making the variole a compound spherulite, while in acid glasses the growths usually take place before other minerals have crystallized out, and are hence not interrupted; they are the first products of crystallization, while in the variolites described they are the last.

Spherical structure in the minette-kersantite rocks has been observed by various writers, but this, as described, is usually a contraction phenomenon occurring on a large scale and brought out by weathering, not a microscopic structure produced by a special process of crystallization. A spherical structure on a minute scale is, however, mentioned by several authors,[1] but, so far as we can learn from the literature, it appears to have been formed by an amygdaloidal filling of vesicular cavities.

Pohlmann,[2] indeed, speaks of a kersantite in which are "concretions" the size of peas, whose center consists of feldspar laths "whose radial structure is not to be mistaken," and between which lie aggregates of chlorite from decomposed augite and biotite. This description seems to agree with the one we have given for the Sheep Creek minette. Pohlmann does not seem to offer a direct explanation for these structures, except to connect them with others containing calcite. Rosenbusch[3] sees in these structures the filling of amygdaloidal cavities; he does not apparently believe that they are of spherulitic nature, since he says "an evident divergent radial structure of the little spheroids is nowhere mentioned" ("auch wird eine evident excentrisch strahlige Structur der Kügelchen nirgends angegeben"), a statement which does not seem to agree with Pohlmann's mentioned above.

As we have not seen the material which these writers have investigated, we can not, of course, presume to offer any opinion as to the origin of the spherical masses they have described, but it is clearly evident that the varioles of the Sheep Creek minettes are not due to the filling of amygdaloidal cavities. They are, on the contrary, an original rock structure, and are quite similar to the variolitic facies of certain diabases, and to be compared to the spherulites found in acid glasses.

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[1] E. Cohen, Kersantit von Laveline: N. Jahrb. Min., 1879, p. 858.

E. Cohen, Ueber einige Vogesengesteine: N. Jahrb. Min., 1883, p. 199.

Liebe und Zimmermann, Jüngere Eruptivgebilde in südwesten Ostthüringens: Jahrb. k. preuss geol. Landesanst. für 1885, p. 178. Berlin, 1886.

Pohlmann, Untersuchungen über Glimmerdiorite und Kersantit Sudthüringens und des Frankenwaldes: N. Jahrb. Min., Bei. Bd. III, 1885, p. 78.

Linck, Geog. petrog. Beschreibung des Grauwackengebietes von Weiler bei Weissenburg: Inaug. Diss. Strassburg i. E. 1884.

[2] Loc. cit. pp. 78, 96.

[3] Massige Gesteine, 3d ed., 1895. p. 519.

We have conceived their mode of formation to be as follows: In the magma, as it was gradually being forced into its final resting place, certain products had begun to crystallize, and it was filled with small crystals of augite, iron ore, and some biotite. On coming in contact with the cold limestones, between whose bedding planes the sheets now lie, a very much more rapid cooling began in the portion adjacent to the contact plane. This forced the remaining portion of the magma into a rapid process of crystallization, and from the minerals already present, which served as centers, rapid growths of feldspar branched out, forming spherulites. These would generally include whatever minerals they found in their way, but it is quite conceivable that while a mica tablet, with its basal plane lying in the direction of growth, would be included, one with the same plane perpendicular to this direction might be pushed along some distance and excluded by the mass of growing fibers. At the same time the mass of feldspathic material growing in this manner would tend to take up those elements necessary for its formation, and to exclude those that were not; hence the residual material would be becoming richer in iron and magnesia, and therefore better fitted chemically for the development of the biotite. The biotite may thus have been excluded from the varioles and concentrated in the interspaces, partly as an already formed mineral and partly as chemical material, some of which formed biotite later. This explanation we believe enables us to understand why the outer zone of the spherulites or varioles is of a lighter color, and why the cement is richer in biotite. Finally, the rate of cooling was such that the residual material now forming the cement did not have time to entirely crystallize, but partly solidified as glass. The whole phenomenon in these minettes, as we understand it from our studies, is clearly that of an endomorphic contact modification of the rock structure, due to quick crystallization induced by rapid cooling.

Some of the observers[1] who have studied the formation of feldspar spherulites in acid glassy rocks have attributed to absorbed aqueous vapors a preponderating rôle in the process. While by no means indicating that such is not the case, the minettes under discussion afford no evidence of their action. That they are not always necessary as a factor in spherulitic crystallization is clearly shown by the occurrence of such bodies, often of great beauty in their development, as an accidental product in artificial glasses.

Exomorphic contact phenomena.—Where the thinner sheets have come in contact with the limestones very little effect has been produced.

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[1] Cross, Constitution and origin of spherulites in acid eruptive rocks: Bull. Philos. Soc. Washington, Vol. XI., 1891, p. 411. Iddings, Obsidian cliff: Seventh Ann. Rept. U. S. Geol. Survey, 1888, p. 255. Iddings, Spherulitic crystallization: Bull. Philos. Soc. Washington, Vol. X, 1891, p. 445.

Immediately next to the contact wall a thin layer of hardened, toughened material has been produced, and the limestone appears to have undergone some recrystallization. As the sheets become thicker this effect increases, and where the beds were shaly they are filled with cavities lined with minute crystals, or are much cracked and the walls of the crevices also filled with crystals. The minerals which are produced by these processes are garnet and pyroxene. The former is of the grossular variety and shows the form of the dodecahedron. The pyroxene comprises the greater part of the altered material and is rarely well crystallized. The contact produced is similar in character to that described on page 540, produced by a closely related igneous rock, and that description includes all that has been observed in the case of the minettes.

The shales on Sheep Creek have been greatly toughened and hardened, and their color is deepened.

Included masses in minette.—Occasionally in the minettes are to be found masses of a plutonic rock which have been brought up from depths below by the ascending magma. One of these is well exposed in the road-cutting previously alluded to. It is a large mass, some 2 or 3 feet in diameter, and is a striking object to find in an intruded sheet at what must be at least a considerable distance from the point of ascent. In the hand specimen it is a grayish rock, rather coarse grained, and of a syenitic aspect. With the lens one sees that it is composed of feldspar and mica, with an occasional grain of pyrite. The feldspar has a waxy appearance, recalling paraffin; it does not possess lustrous cleavages, but is clearly altered. The biotite also has an altered, nonlustrous appearance; the rock, however, does not impress one as having suffered from weathering or atmospheric agencies, but rather from some other cause. Its line of contact with the minette is sharply defined, and the two may even be broken apart at the contact plane with comparatively smooth surfaces. Under the microscope the inclusion is seen to be a mica-syenite of rather coarse grain and of granitic structure, with a gneissoid tendency, as the micas are strung out along certain planes. This does not appear to be due to shearing forces, as the minerals are not at all granulated or broken, but is due rather to an original fluid movement before the rock was wholly crystallized.

The minerals seen under the microscope are biotite, plagioclase, orthoclase, iron ore, and apatite. The biotite has suffered from processes which in the younger extrusive rocks would be called resorption: it appears precisely like many of the resorbed micas which often occur in trachytes; it is partly or wholly converted into opacite or bordered by opacite rims. The feldspars are converted into masses of sericite; occasional unaltered fragments or cores in the crystals permit of the identification of the species, and from these it is seen that orthoclase very greatly predominates. The condition of the plagioclase, together with its small amount, does not permit of accurate determination of the variety, but from the fact that in one example the twin striations which were approximately of equal angle of extinction on either side of the twinning line blended in the position of equal illumination with a Carlsbad twin, so that the whole appeared homogeneous, it must be inferred that it is a very acid one, in the albite-oligoclase group. The occurrence of this syenite as an inclosure in the minette, from the point of view of the genetic relationships of igneous rocks, is very interesting and significant; it shows that this rock exists in the depths, and that the minette is of later origin and connected with it.

The minette itself does not seem to have suffered the least amount of endomorphic modification from its presence; it retains its normal minerals and structure directly to the contact line, and from this we may infer that the mass was taken up while the magma was extremely hot, and that it had acquired very nearly the temperature of the fluid mass before the latter began crystallizing. With regard to the altered condition of the minerals of the syenite, it seems certain that the change in the mica was occasioned by the action of the minette magma. In his valuable work on the inclosures of the volcanic rocks[1] Lacroix speaks of the alteration produced in the biotite of granitoid rocks by the action of an inclosing trachytic magma, and states that the mineral is converted into magnetite, green spinel, new biotite, and often hypersthene. It seems certain to us that heat alone has not produced these changes in the mica, as suggested by Lacroix[2] (at least in the present case), because we should then expect the mica to be equally affected throughout, since it must all have attained the same temperature; whereas in reality some mica tablets are more affected than others but a few millimeters distant from them. If we attribute the alteration to mineralizing vapors in the magma acting with the heat, it is easy to see that some individual micas will be more affected than others, according as the rock varies in its permeability to the vapors from place to place. The new minerals formed are iron ore, new biotite, and a pyroxene in granules.

The conversion of the feldspars into sericite or fine-leaved, fibrous, white mica is probably an effect due in part to the same cause, and possibly also in part to weathering, since the feldspar of the minette appears to be similarly affected, though in less degree.

Alteration of the minettes.—These rocks undergo the normal processes of weathering, the biotite changes to a greenish chlorite, the pyroxene to masses of carbonates and iron ore, while the feldspars change to white mica in part, but mostly to kaolin. After a certain period the feldspathic portion seems to decay more rapidly than the biotites, and as the rock becomes soft and earthy the biotite appears as green scales of chlorite. Eventually the exposure crumbles down into soil, filled with these greenish altered scales, which serve to identify it and show its former character. Many of the intruded sheets have had their outcrops reduced to this condition, making it impossible to obtain good material for investigation.

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[1] Enclaves des roches volcaniques, 1893, pp. 172, 175.

[2] Loc. cit., p. 355.

Minette-like rocks.—Above the series of minette sheets occurring on Sheep Creek, which have been mentioned as exposed in the road-cutting, and below the sheets of the same rock which are seen on the divide, there occur intrusive masses, probably thick intrusive sheets, of a rock which is most closely connected with the minettes and yet differs from them in some particulars. The large talus masses which are found in the woods not far below the divide show a weathered rock of a brownish color, fine, dense, and with decayed ferromagnesian phenocrysts. Under the microscope this rock is seen to consist chiefly of orthoclase, with considerable amounts of biotite and augite, and some hornblende and iron ore. The orthoclase is in short, extended laths, as in the minettes, and gives a trachytoid structure; it is much altered and kaolinized. The augite and biotite are similar in character to those in the minette; the amount of them is much less. They are greatly altered, and converted into masses of chlorite, limonite, carbonates, etc. The hornblende, which is comparatively rare, is generally fresh and of a dirty brownish-green color, with strong pleochroism; some iron ore, apatite, and a few exotic grains of quartz, with mantles of decayed pyroxene and some plagioclase, complete the list of minerals. The material was not suitable for analysis.

The occurrence of this rock is interesting in spite of its altered character, because it furnishes a transition form from the minettes—orthoclase rocks rich in ferromagnesian minerals—into the syenite-porphyries described on page 513, which are orthoclase-porphyries with the ferromagnesian elements greatly diminished. In mode of occurrence in intruded sheets, in their moderate grain, and in the gradation of their mineral and consequently chemical character, these rocks form a closely connected series which are, genetically, intimately related to each other.

Transition from minette into kersantite.—Another transition type of the minette is found in the dark basic dike cutting the syenite which forms the projecting knob of Storr Peak, about 3 miles northeast of Yogo Peak and at the head of one of the forks of Dry Wolf Creek. On a fresh fracture the rock has a very dark-gray color and appears fine grained and exactly like the finer-grained minettes previously described; it glistens from the fine cleavage surfaces of innumerable small biotites. Under the microscope it is found to contain large phenocrysts of augite, with a large amount of greenish fibrous hornblende, plainly secondary after the augite. The augite contains specks of iron ore zonally arranged. The groundmass is composed of biotite of a greenish color and lath-shaped feldspar mixed with considerable of the green hornblende. The greenish color of the biotite would indicate a variety rich in iron, and this seems to to be confirmed by the practically total absence of iron ore in the groundmass. The feldspar is a mixture of the alkaline species with andesine twinned according to the albite and Carlsbad laws. Another of these transition types is found in a black, dense, basic dike cutting the syenite at the Wright and Edward's mine, above Hughesville. The rock contains large glassy, much-crackled inclusions of quartz and of feldspar, which appear to be taken up from rock masses through which the magma has passed on its way upward, in a manner precisely similar to the well-known lamprophyre at Aschaffenburg in Germany.

Under the microscope this dense groundmass resolves into a felt composed of slender microlites of a feldspar varying from labradorite to oligoclase mixed with many of alkali feldspar and granules and formless masses of a completely decayed and altered ferromagnesian component.

NEPHELITE-MINETTE.

The normal minettes of Sheep Creek type, by increase in feldspathic components and consequent diminution of the amount of the ferromagnesian elements, pass into types intermediate to the syenite-porphyries, and in another direction, by increase of plagioclase, they go over into kersantite-like facies. On the other hand, by their assumption of olivine and nephelite there are produced types which, although megascopically retaining the same characteristic minette-like habit, are by the microscope found to be lamprophyric rocks which do not correspond exactly to any hitherto-described rock types. These in their turn grade into rocks in which the minette-like character is lost; they are black or very dark, dense lamprophyres, occurring in dikes, and although they can not be assigned to any definite type, in the present systems of classification, they clearly belong in the monchiquite-alnoite series of Rosenbusch, and have perhaps their closest analogies in some of the rocks described as "monchiqnites." The most characteristic type of nephelite-minette occurs in a broad dike or intrusive mass cutting the limestones in the saddle or low point in the spur running eastwardly from Bandbox Mountain. The rock is of a clear dark-gray color, thickly mottled with small glittering tablets of black biotite, which occasionally reach 5 mm. in diameter, and with light-brownish spots which are altered olivines.

In thin section the following additional minerals are found to be present: augite, iron ore, apatite, alkali feldspar, nephelite, and sodalite.

The augite is a clear, pale-greenish brown in the section, has a good cleavage, and shows no inclusions. It is often fringed by granules of iron ore. The phenocrysts are 1 or 2 mm. in length, the habit broad and stout, and the development of the crystal faces renders them idiomorphic. The phenocrysts are moderately common. Augite of a similar character is freely and abundantly scattered through the groundmass in small short prisms and rounded anhedral grains.

The biotite which occurs so abundantly through the groundmass is in rather slender foils, seldom in broad tablets. It is intensely pleochroic, between a very deep olive-brown and a pale yellow. In addition to this normal variety there occur spots in the rock which contain local enrichments of biotite in larger leaves and tablets of peculiar color and appearance. Within it is of a light olive-green color, mottled and clouded with areas of brown, and fringed by a zone of brown on the outer edge; its pleochroism varies between the olive green and a pale-brownish color. It is everywhere thickly spotted by inclusions of iron ore.

The feldspar is entirely an untwinned alkali variety, found in small grains and laths and mixed with irregular areas of nephelite and small, pale-brownish, rudely circular masses of sodalite, which are, of course, isotropic between crossed nicols. The presence of the nephelite is proved by the ready and abundant gelatinization of the powdered rock in extremely dilute nitric acid, and by the faint negative uniaxial cross of basal sections between crossed nicols; the sodalite is shown by the strong reaction for chlorine given by the solution on qualitative testing.

Except for the alteration of the olivine, which appears to be quite thoroughly altered to a micaceous substance which may be iddingsite, the rock appears quite fresh and unchanged. In structure the rock is porphyritic, but holocrystalline, and in ordinary light it appears of a strongly minette-like character, due to the abundant foils of biotite, though rather richer in augite than a truly typical minette. It is clearly and pronouncedly a lamprophyre, and the name of nephelite-minette seems to best define it. It appears to be a transition form from the regular minettes into the monchiquite alnoite-lamprophyre series of Rosenbusch.

CONTACT PHENOMENA.

The most marked case of the metamorphism induced by the lamprophyres which has come under our notice is that produced by the rock described above. Here a mass of the limestone into which the igneous rock has been intruded has been split off and immerged in the fluid mass. As a result it has been subjected to a more intense degree of contact metamorphism than we have seen exhibited in any other locality, and as it shows the character of the phenomenon on a large scale and with a more perfect development of new minerals, we have been led to study it in some detail, since its description serves to cover all of the less striking cases previously mentioned.

The lime rock has become hard, dense, tough, and of a somewhat greenish color. It has been much cracked, and these cracks are often filled by small dikelets or apophyses from the igneous rock. Often these little tongues or "flames" are but a few millimeters in width. In other places the rock is hollow and rather cavernous and the cavities are completely studded by the brilliant facets of very small, often minute, bright-green diopside crystals. The pyroxene is characterized by the frequent occurrence of the forms m (110), λ (331), and o $(\bar{2}21)$, and is similar to the pyroxene occurring in the limestone altered by contact metamorphism of the diorite at Blackhawk on Castle Mountain, which has been described and figured by the author.[1] Associated with the pyroxene are small, often brilliant crystals of a wine-colored grossular garnet which shows only the planes of the dodecahedron and is at times two or three millimeters across the diameter of the crystal.

Thin sections cut across the altered rock and the narrow dikelets, thus showing the contact plane of the two, exhibit several interesting features under the microscope. The minette rock whose normal character is somewhat variable, as previously mentioned, seems to maintain its full size of grain to the contact wall. This is no doubt due to the mass of limestone having been an inclusion and not a limiting contact wall. It would therefore readily become so greatly heated as not to chill the magma and interfere with the process of crystallization. As the rock approaches the contact it becomes surcharged with lime, which marks itself by the production of great quantities of augite. The augite is present in large crystals and in great quantities of minute rounded anhedra. It finally becomes enormous in amount, and the large biotites inclose great quantities of these small grains poikilitically. A considerable number of sodalites close to the contact edge are also noticed. Although this contact edge, as seen by the eye alone, is a very sharp line, the microscope shows that there has been considerable penetration of the lime rock by the igneous magma. It penetrates in narrow threads and tongues, and although at the edge there is a great predominance of augite in the lime rock, this is mixed with patches and masses of alkali feldspar and biotite. These gradually fade out, and the rock becomes an almost solid mass of small pyroxenes in round grains, with an occasional biotite flake; the minute interstices between the crowded grains are filled with a colorless isotropic substance of low refraction whose exact nature can not be determined. This appears to be the dominant type of the included mass.

VOGESITE.

Several types of minettes have been found in which the augite has apparently been converted into hornblende. Since in all the minettes from this district the proportion of augite is large, they should be termed augite-minettes. The hornblende, therefore, plays a conspicuous rôle, and whether such rocks should be called vogesite or not is an open question; it being understood, of course, that the secondary hornblende predominates over biotite. They might, perhaps, be called pseudo-minettes or meta-minettes, indicating that an alteration of a prominent ingredient has taken place.

In one or two instances, however, types occur in which it can not be said, from any evidence afforded by the microscope, that the hornblende is secondary; and since the rocks are of typical lamprophyre habit and method of occurrence, and are composed of predominant hornblende and alkali feldspar, they may well be termed vogesites. The best instance of this type is found in intruded sheets in the Cambrian on Dry Belt Creek several miles below Barker. The road-cutting on the side hill has afforded fairly fresh material. The rock is of a gray color, with an olive tone, and weathers with a brownish crust. It is cracked by prismatic jointing and on breaking one of the pieces it can be seen that a zone of alteration extends from each joint face inward, leaving only the central portion as an unaltered core. The grain is quite fine and the rock tough and hard to break. With the lens it appears distinctly crystalline, but contains no phenocrysts of any kind. An occasional exotic fragment of included quartz or feldspar brought up from the gneiss below was noted.

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[1] Weed and Pirsson, Geology of the Castle Mountain mining district: Bull. U. S. Geol. Survey No. 139, p. 161.

Under the microscope the rock is found to consist of a mixture of greenish-brown hornblende and alkali feldspar, with accessory plagioclase, apatite, and iron ore, and with calcite, chlorite, and quartz as secondary alteration products.

The hornblende is moderately fresh. It occurs in slender prisms, and its color varies from place to place from green to brown. It has a small angle of extinction and moderately high birefraction. It does not appear to be an alkali-bearing variety. It is present in very large amount; a rough estimate would place the proportion of hornblende to feldspar as two to three.

Of the feldspar an unstriated alkali variety decidedly rules; it is considerably altered, and filled with sericite leaves. It has a long, lath-shaped form, much like the hornblende, and the two are interwoven in a somewhat trachytic structure, with granules of iron ore, apatite, and decomposition products, such as chlorite, filling the interspaces.

The plagioclase is also lath-shaped, like the alkali feldspar, but, if anything, more altered, so that its determination is not so satisfactory as could be wished. Nevertheless, since all sections of it seen extinguish nearly parallel with the nicol, no matter what twinning is present, we may safely conclude that it is an oligoclase.

The quartz appears in the triangular interspaces between the feldspars much as in many trachytes. It appears in part secondary, but much of it is clearly of primary origin and the last mineral which crystallized.

The structure of the rock is dominated by the lath-shaped hornblendes and feldspars; it is the structure of many well-known types of lamprophyres, and is somewhat trachytic. A rock of quite similar type occurs intruded in Cambrian shales on Belt Creek about 3 miles above Monarch; the hand specimen is lighter in color and the rock more coarsely crystallized; it forms a transition to a fine-grained syenite very rich in brownish hornblende.

ANALCITE-BASALTS.

As previously stated, the nephelite-minette forms a transition type from true minette to a series of lamprophyres which are found most abundantly cutting the limestones forming the top of Bandbox Mountain and the divide running north and connecting it with Steamboat Mountain. These rocks are analcite-basalts, the type of which was first described by Lindgren[1] from the Highwood Mountains, Montana.

BANDBOX MOUNTAIN TYPE.

The rock forming the narrow dikes on Bandbox Mountain is generally more or less decayed, but in one instance good fresh material could be obtained. It strongly resembles the nephelite-minette in appearance, is a dark basic-looking rock, with great numbers of large, fresh olivines, small mica plates, and occasional augites as phenocrysts.

Under the microscope the same minerals are to be seen lying in a colorless base. The large olivines are very fresh, clear, and limpid. The occasional large augites are also clear and nearly colorless; they appear to be of the diopside variety. The biotite is very peculiar. It has the striking red-brown color often seen in theralitic and leucitic rocks, but of so pale a tone that it appears a pale orange-brown; the pleochroism, while marked, is therefore unusual.

Rays parallel to $c =$ light yellow-brown.
Rays perpendicular to $c =$ colorless.

The larger crystals of this mica, which may properly be termed phenocrysts, are at times broken and bent and have embayed portions. The olivines and augites are also often broken and the pieces slightly separated from one another, the irregular contours of one piece exactly corresponding to those of the one adjoining. This would seem to point to an earlier period of formation for these crystals, which have become cracked and separated in the upward movement of the inclosing viscid mass. It is noticeable that these interspaces in the case of the olivines are filled with the peculiar mica already mentioned, while a narrow fringe or mantle of it surrounds all of them on the outside. We are inclined to believe, from its color and from the chemical relations shown in the analysis, and a consideration of the minerals present, that it is a biotite rich in alumina and poor in iron.

The minerals which have been described are lying in what may be termed a groundmass, consisting chiefly of pyroxene, with a considerable amount of the mica already described in flakes and scattered shreds, cemented by a pale-brownish isotropic base. The second generation of pyroxene occurs in small, slender prisms, having a colorless diopside core, surrounded by a deep-green mantle of ægirite. The brownish base examined with very high powers is really colorless, but dotted with innumerable small brownish specks, which give it, under low powers, a general brownish tone. In ordinary light it appears much like a somewhat kaolinized feldspar. With a strong illumination between crossed nicols, it is seen not to be wholly isotropic everywhere but to have in places a feeble aggregate polarization; and it often contains minute flecks of brightly polarizing substances, perhaps due to calcite or muscovite. As will be shown later, this base consists of analcite, in agreement with what has been demonstrated for similar rocks from other regions.[1]

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[1] Tenth Census United States, Vol. XV, 1886, p. 727. Eruptive rocks from Montana: Proc. California Acad. Nat. Sci., ser. 2, Vol. III, 1890, pp. 39-57.

The essential character of the rock is given to it by the large olivines lying in the groundmass of interwoven small, slender pyroxenes with their green rims and the dusty brownish base of analcite cementing the whole, touched up here and there with the pale-orange biotites. The rock, from the presence of this mica and the green-rimmed pyroxenes, has an appearance which recalls that of some of the fine-grained theralites from the Crazy Mountains. (See Pl. LXXVI, *B*.)

An analysis of this interesting type (No. 576) by Dr. W. F. Hillebrand gave the results shown below in No. I:

Analyses of analcite-basalts from various localities.

Constituent.	I.	II.	III.	IV.	V.	VI.	VII.
SiO_2	48.39	46.48	42.46	43.50	45.59	45.58	0.8065
Al_2O_3	11.64	16.16	12.04	18.06	12.98	15.87	.113
Fe_2O_3	4.09	6.17	3.19	7.64	4.97	4.65	.026
FeO	3.57	6.09	5.34	7.52	4.70	6.37	.050
MgO	12.55	4.02	12.40	3.47	8.36	8.32	.314
CaO	7.64	7.35	12.14	13.39	11.09	9.91	.136
Na_2O	4.14	5.85	1.21	2.00	4.53	3.42	.067
K_2O	3.24	3.08	2.68	1.30	1.04	1.61	.034
H_2O + 110°	2.56	4.27	4.03	1.22	3.40	a3.14	.142
H_2O − 110°	.28	....	....	....	.51	....	....
TiO_2	.73	.99	2.47	2.10	1.32	Undet.	....
CO_2	None.	.45	.55	....	....	....	....
P_2O_5	.45	(?)	.84	(?)	.91	(?)	....
Cl	Trace.	....	None.	....	.05	....	....
SO_3	.08	....	None.	....	b.03	....	....
Cr_2O_3	.07	....	....	....	....	....	....
MnO	Trace.	....	.16	....	.14	Trace.	....
NiO	None.	....	....	....	....	....	....
BaO	.32	(?)	Undet.	(?)	.13	(?)	....
SrO	.15	(?)	Undet.	(?)	.12	(?)	....
Li_2O	Trace.	....	Trace.	....	Trace.	....	....
Total	99.90	100.91	99.51	100.20	99.87	98.86	....

a. Ignition includes CO_2, etc. b ZrO_2.

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[1] Pirsson, On the monchiquite or analcite group of rocks: Jour. Geol., Vol. IV, 1896, p. 679. Cross, Analcite-basalt from Colorado: ibid., Vol. V, 1897, p. 684.

I. Dike of analcite-basalt from Bandbox Mountain. W. F. Hillebrand, analyst.
II. Analcite-basalt (monchiquite), Santa Cruz, Brazil. Hunter and Rosenbusch, Tscher. Mitt., XI, 1890, p. 445 (see also Jour. Geol., Vol. IV, 1896, p. 679). M. Hunter, analyst.
III. Analcite-basalt (monchiquite), Castle Mountain district, Montana. Weed and Pirsson, Bull. U. S. Geol. Survey No. 139. L. V. Pirsson, analyst.
IV. Analcite-basalt (monchiquite), Magnet Cove, Arkansas. Williams, Igneous Rocks of Arkansas, p. 295. W. A. Noyes, analyst.
V. Analcite-basalt, The Basin, Cripple Creek district, Colorado. Cross, Jour. Geol., Vol. V, 1897, p. 689. W. F. Hillebrand, analyst.
VI. Analcite-basalt (monchiquite), Shelburne Point, Vermont. Kemp, Bull. U. S. Geol. Survey No. 139, by Weed and Pirsson, Geology Castle Mountain mining district. H. T. Vulte, analyst.
VII. Molecular ratio of oxides in No. I.

It will be noticed that the rock has the chemical characters of the lamprophyre group—low silica and modern alumina, with rather high alkali for so basic a type, and, at the same time, high lime and magnesia. In connection with the analysis, we have given all the analyses of rocks of this type which have been classed as monchiquites that we have been able to find in the literature. It will be seen that it does not agree in its chemical relations very closely with any of them, nor, indeed, for that matter, do they agree very closely with one another. This is due to the fact that under the heading of ferromagnesian minerals in a colorless isotropic base quite different varieties and proportions of minerals may be assembled; the composition of the base may be variable, consisting of different isotropic minerals, analcite, leucite, sodalite, etc., and its proportion to the dark minerals which are present may also vary. The ratios given under VII furnish a means of determining the character of the isotropic base. Neglecting small quantities of nonessential minerals, we may assume the rock made up of diopside, olivine, biotite, and the base. All of the lime is in the pyroxene, which gives the measure of its amount. The biotite produces some uncertainty, but we may consider it made up of an olivine molecule $(MgFe)_2SiO_4$ and a feldspathoid in which $K_2O:Al_2O_3::1:1$. The ferrous iron molecules may then be added to the magnesia, a correspondent for the lime (as augite) deducted from the sum, and the remainder of the (MgFe)O molecules considered olivine. This leaves $(Na_2O + K_2O):Al_2O_3:SiO_2::.101:.113:420$, which is—1.1:4.1, or in round numbers, 1:1:4, and this shows that the base has the general formula $RAl(SiO_3)_2$. When we consider the ratio of the soda to the water we find that it is $0.067:0.142 = 1:2.1$ or 1:2, and consequently it is clear, since the biotite contains a considerable part of the potash; and that the isotropic base has the composition $NaAl(SiO_3)H_2O$, or is made up of analcite. When we reflect that this is only an approximation, that the water in the biotite and the ferric iron present as ægirite (though these two errors tend to counterbalance each other, since ægirite requires $Na_2O:Fe_2O_3 = 1:1$, and biotite requires $H_2O:Al_2O_3::1:1$) have not been considered, the agreement of these ratios is very remarkable, and it is clear that they are not accidental; and the fact of the isotropic base being made up of analcite may be considered demonstrated. Thus, all things considered, the rock shows that it is an analcite-basalt and should be classified as such. Its petrologic affinities will be pointed out later when some other related types have been considered.

EUREKA DIVIDE TYPE.

It has been mentioned that on the divide between Bandbox and Steamboat mountains a series of dikes occur. Like those on Bandbox Mountain, they are narrow and of dark basic rocks of basaltic character. They do not show any large phenocrysts, but are quite dense, of very dark-gray color, and one sees only the light reflected from numerous cleavage surfaces of minute biotites; they thus have a strong minette-like habit.

Under the microscope they are found to consist of biotite and pyroxene in small crystals thickly crowded in a colorless base; the large olivines of the previous type are entirely wanting. The biotite is of the same character as in the former variety, and the pyroxene has the same form and mantle of ægirite. The rock thus appears very similar, but without the large phenocrysts; there appears to be more variability in size of the second generation of pyroxene and biotite, and relatively more of them in proportion to the amount of groundmass; the amount of ægirite is also less. The colorless groundmass is also thickly spotted with minute pale-brown specks that appear like kaolin; in places it shows a feeble aggregate polarization between crossed nicols.

One peculiarity that distinguishes this from the former type is that its surface shows here and there minute round spots of a white mineral. Under the microscope these spots are without crystal form and appear composed of an isotropic mineral; the other components frequently project into them; and they frequently contain bright polarizing specks, which in convergent light give the negative, uniaxial, ringed cross of calcite. The rock powder is found to gelatinize with very dilute nitric acid, and qualitative tests show the absence of chlorine and the presence of considerable sulphuric anhydride in some sulphate. The colorless mineral is probably nosean, and that it is rich in soda is shown by the fact that wherever the pyroxenes project into it they are invariably tipped with deep-green ægirite, although the outer portion may be almost entirely a colorless diopside. Similar facts regarding a local enrichment of soda have been described by Cross.[1]

In this connection an interesting fact in relation to these rocks, as well as the Bandbox Mountain type, should not be passed by without mention, and this is the total absence of iron ore in them in spite of the very considerable amount of both ferrous and ferric oxides shown by the analysis previously given. The ferrous oxide has gone into olivine and pyroxene, the ferric into ægirite and biotite. The base consists of various isotropic minerals, partly altered; analcite is undoubtedly present, and nothing more definite can be stated concerning it.

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[1] Geology Cripple Creek district: Sixteenth Ann. Rept. U. S. Geol. Survey, Part II, 1895, p. 35.

The only occurrence of a lamprophyre which we have been able to find in the literature, similar in character to this just described, is one from Umptek which has been studied by Hackman.[1]

This consists also of olivine, biotite, and pyroxene in an isotropic base (probably of analcite), and the pyroxene has also the ægirite rims. Hackman, adverting to the character of the pyroxene, which differs so much from the basaltic variety found in the types described as monchiquites, is inclined to believe that these rocks should not be placed in the same class with them. With more or less uncertainty regarding the character of the base existing, it appears to the writer that the formation of a new class based on the distinction of a variable pyroxene seems to be hardly advisable, and he has followed Hackman's conservative course.

BARKER TYPE.

A rock which is closely related to the forms just described occurs as a dike on the north side of Dry Fork of Belt Creek, above the town of Barker. It is a dark, dense, basic-appearing variety, and the section shows a considerable number of rather small olivines lying in a felt composed of slender, colorless prisms of augite cemented by an isotropic base. The olivines are fresh and present no particulars worthy of mention; they are accompanied by some iron ore and apatite. The augite, with low powers, shows the mossy appearance so frequently presented by the slender microlites of ægirite in tinguaites; it is a sort of felt, composed of very small, long, slender microlites densely interwoven, of a colorless pyroxene which only in a few cases was seen to pass into green ægirite. When this mesh is studied with high powers occasional minute scraps of a brownish mineral, which is thought to be biotite, are seen; the particles are so small that the determination must be considered doubtful. The base which cements the minerals is colorless, and though generally isotropic it shows in places a feeble polarization; it is probably of analcite.

BIG BALDY MOUNTAIN TYPE.

This rock was not actually found in place, as the whole surface of the exposed laccolith on the south side, where the specimens were obtained, presents a smooth surface formed of large, flat-joint plates, the outcrops having broken down into slide rock. The course of the dikes, which are seen as black lines crossing the white walls of the enormous amphitheaters on the east side, is here readily perceived by the dark fragments mixed with the light-colored porphyry of the main rock. On a fresh fracture the rock is a very dark stone color, or grayish black, and very dense in grain; only occasional small spots of a dark-brown mineral, an altered olivine, are to be seen. The rock has, indeed, a pronounced basaltic habit.

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[1] Nephelinsyenitgebiet auf der Halbinsel Kola, Ramsey und Hackman: Fennia, 11, No. 2, 1894, p. 178.

In the section the olivines are found to be quite rare; they range from 1 to one-half millimeter in diameter and are nearly always serpentinized; with this exception the rock is very fresh. The most common mineral and the one which forms by far the greater bulk of the rock is a pale brownish-green pyroxene, so light in color in the section as to be nearly colorless. It is in rather slender, square prisms, and ranges in size from 1 to one-tenth millimeter in length; it contains numerous pale-brownish inclusions of glass. A moderate amount of iron ore is scattered around among the pyroxenes. These minerals are lying thickly crowded in a groundmass which is filled with very great numbers of flat tabular microlites of a brownish-olive augite; these latter vary in size up to the dimensions of the smallest of the colorless pyroxenes already mentioned. The base which cements all of the minerals together is a colorless isotropic substance filled with minute dusty specks of a brownish or blackish color, which are no doubt of a ferruginous nature or separated particles of ore. The general effect of the section with a moderately low power is precisely that of an augitite, great quantities of augite in idiomorphic crystals lying in a brownish base, which is isotropic.

An analysis of this type by Dr. W. F. Hillebrand gave the results given in Column I:

Analyses of lamprophyres.

Constituent.	I.	II.	III.	IV.	V.
SiO_2	48.35	45.04	42.03	48.43	0.806
Al_2O_3	13.27	16.04	13.60	11.41	.129
Fe_2O_3	4.38	7.10	7.55	12.32	.027
FeO	3.23	8.23	6.65	.64	.045
Mg	8.36	4.46	6.41	8.23	.209
CaO	9.94	10.19	14.15	9.97	.179
Na_2O	3.35	6.11	1.83	3.59	.057
K_2O	3.01	2.85	.97	3.21	.032
$H_2O + 110°$	2.89	.33	1.08	1.33	....
$H_2O - 110°$	.90	....	....	....	....
TiO_2	.52	(?)	3.70	(?)	....
P_2O_5	.40	(?)	.57	(?)	....
CO_2	.30	....	FeS_2, .56	CO, trace.	....
Fl	.25	....	SO_3, .08	....	....
Cr_2O_3	Trace.	....	NaCl, .05	....	....
NiO	.04	....	....	....	....
MnO	.19	....	Trace.	.34	....
BaO	.54	(?)	(?)	(?)	....
SrO	.09	(?)	(?)	(?)	....
Li_2O	Trace.	....	....	....	....
Total	100.01	100.35	99.23	99.47	....
O = Fl	.10	....	....	....	....
	99.91	....	....	....	....

I. Analcite-basalt dike rock of Big Baldy Mountain, Little Belt Mountains. W. F. Hillebrand, analyst.

II. Augitite, Upper Picos vale. Vulcane der Capverden. Doelter, 1882, p. 143. C. Doelter, analyst.

III. Fourchite, Fourche Mountain, Arkansas. Igneous Rocks, Arkansas. J. F. Williams, 1890, p. 111. Brackett and Noyes, analysts.

IV. Vogesite, Forsthaus Welschbruch, Alsace. Rosenbusch, Steiger Schiefer, 1877, p. 301. H. Rosenbusch, analyst.

V. Molecular proportions of No. I.

The analysis shows strongly the characters of the lamprophyre group—high lime, iron and magnesia, low silica and alumina, and moderate alkalies.

Considering that the rock is composed essentially of augite and an isotropic base which has the chemical composition given above, we have not been able to find in the literature any type which precisely corresponds with it. Two varieties of rocks of this class are compared, as to their chemical composition, under II and III, for the sake of example. The rock described by Doelter consists mainly of augite in a "glass" base, with minute amounts of other minerals; that by Williams consists of augite in an "altered glass base." The former is an extrusive. With both, the type under discussion shows certain analogies, but at the same time important variations. When one compares it with the analyses given on page 544, the same is found to be the case; yet according to our existing systems of classification (and especially when one takes into account its generic relations) it appears to belong best under the camptonite-alnoite series of Rosenbusch. From the chemical point of view the hornblende-vogesite whose analysis is given under IV in the above table agrees with the Big Baldy Mountain rock better than any we have been able to find. The agreement, except as to the iron, is quite remarkable indeed, and it must be confessed that the relations of the two iron oxides for a rock of this class, as given in Analysis IV, are not above suspicion. The ferrous oxide must certainly be too low; the ferric, too high. Taking this into consideration, the agreement would be even closer. It shows how extremely similar magmas may crystallize into quite different minerals.

If we consider the molecular ratios given in the last column of the preceding table, they may be arranged as follows with respect to the minerals shown to be present:

$$\left.\begin{array}{ll} Fe_2O_3\ldots\ldots & 0.027=1 \\ FeO\ldots\ldots\ldots & .027=1 \end{array}\right\}\text{Magnetite.}$$

$$\left.\begin{array}{ll} \left.\begin{array}{ll} FeO\ldots\ldots\ldots & .018 \\ MgO\ldots\ldots & .030 \end{array}\right\} & 2 \\ SiO_2\ldots\ldots\ldots & .024=1 \end{array}\right\}\text{Olivine.}$$

$$\left.\begin{array}{ll} CaO\ldots\ldots\ldots & .180=1 \\ MgO\ldots\ldots & .180=1 \\ SiO_2\ldots\ldots\ldots & .360=2 \end{array}\right\}\text{Diopside.}$$

From the above there remains over—

$$SiO_2 = 0.424.$$
$$Al_2O_3 = 129.$$
$$(Na_2O + K_2O) = .089.$$

Of course such a computation must be considered as only rudely approximate; there is an excess of alumina over the alkali, and it is therefore probable, as usually happens in such cases, that some of it has found its way into the augite. The calculation is sufficient to show, however, that if an alkali-alumina silicate had formed as a residual product of crystallization, it must have been mainly one of the feldspathoid group, low in silica and rich in alumina and alkalies. This group, it will be remembered, is composed mainly of isotropic minerals, as leucite, analcite, sodalite, etc. The ratios, indeed, approximate to the relation

$$Na_2O + K_2O : Al_2O_3 : S : O_2 :: 1 : 1 : 4,$$

which would furnish a silicate of the formula $(NaK)\,Al\,(SiO_3)_2$, which is that of leucite, or, with the addition of water, of analcite.

Of the very considerable amount of water shown by the analysis it may be said that there is no apparent alteration product which could account for it except the serpentinized olivines, and they are entirely too minute in amount to furnish more than a very small fraction of it. It must therefore belong to the isotropic base, and could be furnished by analcite. That it is the latter is shown by the molecular ratios of the water to the other components—

$$(Na_2O + K_2O) : Al_2O_3 : SiO_2 : H_2O :: .089 : .129 : .424 : .210,$$

or approximately 1 : 1 : 4 : 2, which is the ratio required by analcite.

The rock powder when treated with very dilute nitric acid is found to gelatinize readily and abundantly. This could not be due to leucite, which does not gelatinize, though decomposed with acid, but is undoubtedly due to analcite. In this connection it is interesting to note that the molecular ratio of the soda to the water in the fourchite of Williams is .030 : .060 = 1 : 2, which is the ratio required by analcite, and undoubtedly this mineral is present in the base of his rock.

From the molecular ratios furnished by the analysis it may be easily calculated that our rock contains—

	Per cent.
Iron ore	6.7
Pyroxene	39.6
Olivine	4.2
Base (mostly analcite)	49.5
Total	100.0

RELATED TYPES WITH POLARIZING BASE.

It will be noticed by reference to the geologic map that the great intruded stock or mass of which Yogo Peak forms the western extremity is narrowed down at the head of Yogo Gulch to a dike-like character. As previously described, the western limb of this mass practically ends at this point in a mass of shonkinite, and then thins out into the dike which runs along the crest of the divide until it widens into the Sheep

Mountain portion. The exposures at this point hardly warrant us in stating positively that the dike forms an actual apophysis of the mass and is not a separate intrusion, but the general relation of the intruded bodies inclines one strongly to the belief that it is an apophysis—a connecting link between the masses, and not a separate intrusion.

The rock forming this dike is dense black and similar to the lamprophyric types previously described. In the section are found olivine and augite in a colorless base, thickly peppered with minute ore grains. In places the ore grains are wanting, and their place is filled by scattered leaves or skeleton crystals of biotite. The base when examined between crossed nicols presents a mosaic of low polarizing grains of great fineness mixed with isotropic ones. The effect with a low power is that of an aggregate polarization. This may be due in part to zeolitization, but may equally well be a mixture of analcite with nepheline or orthoclase, or both. The rock also contains a number of olivines and augites of large size, which are deeply corroded and bordered by heavy black opacite rims. They are probably of intratelluric origin and have suffered, in later movements of the magma, a partial resorption. An exact analogue of this type, except for the corroded olivines and augites, occurs in the drift brought down from Big Baldy Mountain in Butcherknife Creek. The rock was not found in place, but undoubtedly comes from some basic lamprophyre dike.

These types appear to be closely related to the absarokites of Iddings,[1] which seem to belong in the monchiquite-alnoite series of lamprophyres of Rosenbusch,[2] with a base composed of alkali feldspars more or less mixed with feldspathoid minerals. In the majority of the types described as monchiquites the base is an analcite, as we have shown elsewhere;[3] in the camptonites it is a soda-lime feldspar, and in the absarokites it is essentially orthoclase. If the base were nephelite the rock would have the essential character of many nephelite-basalts, and it is evident that these rocks with varying developments of the feldspathoid minerals, but which are composed chiefly of ferromagnesian silicates, will show transitions into the various types of alkaline basalts, whose effusions are a common feature of many regions.

TRANSITION FROM ANALCITE-BASALT TO MINETTE (INCLUDING THE SAPPHIRE-BEARING ROCK OF YOGO GULCH).

On the long ridge which extends eastwardly from Bandbox Mountain, and which forms a spur between the head branches of Running Wolf Creek, and in a deep saddle of which occurs the nephelite-minette previously described, are found several dikes cutting the limestone. One of these dikes is found to be composed of pyroxene and biotite, with large pseudomorphs of serpentine after olivine, lying in a colorless isotropic base. The pyroxene is of a pale-brownish variety, the biotite the usual deep-brown pleochroic kind found in igneous rocks. The base has in places a feeble aggregate polarization. A considerable amount of iron ore is present. Disregarding the olivine, the character, relations, and amount of the minerals are such that, seen in ordinary light, the section strongly recalls many of the minettes which have been previously described; the use of the analyzer shows, of course, that the base is not composed of feldspar. From the actual character of its minerals the rock is most nearly related to the analcite-basalt which has been previously described.

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[1] Jour. Geol., Vol. III, 1895, p. 935.

[2] Mass. Gesteine, 3d ed., 1895, p. 535.

[3] Jour. Geol., Vol. IV, 1896, p. 679.

The same type occurs also in the form of sheets intruded in the Cambrian beds at the very head of Belt Creek, the structure and relation of the minerals being precisely similar; the groundmass giving a feeble aggregate polarization, but presenting in many places minute spots of a doubly refracting colorless mineral, which may be orthoclase or nephelite.

SAPPHIRE ROCK OF YOGO GULCH.

By far the most important occurrence, from an economic standpoint, of these basic lamprophyric types is that of the corundum or sapphire-bearing rock near the mouth of Yogo Gulch. A preliminary account of this rock and its sapphires has been already published elsewhere,[1] but on account of its economic bearings and in the hope that its description may aid in the search for similar occurrences in the region it is now repeated with additional details.

The rock is of a dark-gray color and has an uneven fracture. It contains small, light-green or white included masses, which form its most conspicuous feature, and these angular inclusions are pieces of limestone broken off and carried upward by the fluid rock in its ascent. They vary in size from those of microscopic dimensions to some that are half an inch or about a centimeter across. Many of them consist entirely of calcite, while others appear to be made up of a pale-green mineral, which is pyroxene. The largest inclusions, especially those of quartz, show a reaction rim of the same green pyroxene, the rim being about 1 mm. thick, while the entire center is of calcite with scattered prisms of the pyroxene. The rock shows only scattered tablets of mica as phenocrysts 2 or 3 mm. in diameter, while the groundmass glitters with minute flecks of biotite, and considerable pyroxene is seen.

Microscopic characters.—In thin section the rock at once exhibits its character as a dark, basic lamprophyre, consisting mainly of biotite and pyroxene. There is a little iron ore present, but its amount is small and much less than is usually seen in rocks of this class. The biotite is strongly pleochroic, varying between an almost colorless and a strong, clear, brown tint. It occurs in ragged masses, rarely showing crystal outline, and it contains a large amount of small apatite crystals. The pyroxene is a pale-green diopside filled with many inclusions, now altered, but probably originally of glass; in some crystals these inclusions are so abundant as to render the mineral quite spongy. The grains sometimes show crystal form, but are mostly anhedral and vary in size, though the evidence is not sufficient to show two distinct generations.

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[1] Am. Jour. Sci., 4th series, Vol. IV, 1897, p. 421.

These two minerals lie closely crowded together, and no feldspars are seen in the rock. The small interstices between them are filled with a clouded, brownish, kaolin-like aggregate, which appears to represent some former feldspathic component, possibly leucite, perhaps analcite. The rock appears to have its closest affinities in the analcite-basalt group, of which it may be considered a basic, somewhat altered, type. The abundance of biotite shows its relation to the minettes, but the rock is much richer in the ferromagnesian components and lacks the feldspar of the minettes. It has evidently a close affinity with the minettes and shonkinite of the region, and is clearly of the same magma. It has the same richness in biotite and pyroxene as these, but differs in the feldspathic component. Yogo Peak, with its shonkinite, is but a small number of miles distant from the locality.

Some calcite in agglomerated granules is also seen in the section, and this, as is so often the case in lamprophyres, does not appear as if secondary in origin, and is probably due to limestone fragments picked up, as previously mentioned.

Origin of the sapphires.—The occurrence of such well-crystallized corundum in a basic igneous rock is of great interest. It seems clear, from the many different ways in which this mineral occurs, that there must be several methods in nature for its formation. The association with metamorphic rocks such as gneisses, schists, etc., is well known, and its occurrence with granites is also not uncommon. In all these cases, however, the association is with older metamorphic or granular crystalline rocks, and we know of its occurrence in more recent, undoubted basic igneous rocks in but few cases. Lagorio,[1] in an article to be mentioned presently, gives a list of the known occurrences of corundum in igneous rocks, their tuffs, ejected fragments, and contact zones.

By a series of important and interesting experiments Morozewicz[2] showed that molten glass of a basic character dissolved alumina readily and in large quantity, and from this, on cooling, corundum and spinel crystals separated out. Lagorio,[3] in commenting on these results and adding details of some experiments of his own, showed that the former idea which had been held concerning the origin of corundum in igneous rocks should now no longer be urged. This idea was that such corundums had been torn loose from some place below where they had previously existed, and, being infusible, had spread themselves through the magma. Others again recognized in these corundums infusible but recrystallized portions of rock fragments inclosed in the magma, other portions being converted into spinel, cordierite, etc. Lagorio points out, however, that this could not be the case, as corundum dissolves in molten glasses; and he calls attention to the confusion which has existed between fusibility of compounds in molten masses and their solubility in the same, the two being quite distinct. The characteristic form of corundum occurring with igneous rocks is the thin, flat, hexagonal table with low rhombohedron, described in a subsequent extract.

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[1] Zeitschr. für Kryst., Vol. XXIV, 1895, p. 285.
[2] Ibid., Vol. XXIV, 1895, p. 281.
[3] Op. cit.

This occurrence at Yogo Creek is an important addition to the list of pyrogenetic corundum. The clear-cut form of the crystals and their general distribution show that they have crystallized out of the magma with as much certainty as the well-formed phenocrysts of feldspar in a porphyry betray their origin.

The general character of the rock, however, and its close relationship to the minettes and shonkinite of the region, show that it could not originally have been sufficiently rich in alumina to have allowed a general separation out of corundum. The condition of it, as mentioned above, shows that the magma took up great quantities of inclusions from the sediments through which it passed. Among these sediments must have been a considerable thickness of clay shales. The liability of such beds to be shattered by igneous rocks ascending through them and included as fragments has already been shown elsewhere.[1]

Such included fragments of shale, if the magma maintained its heat sufficiently, as it naturally would if confined in the form of an intruded mass, would eventually be dissolved, as the experiments described show. There would thus be formed local areas in the magma very rich in alumina, which on cooling would allow crystals of corundum to separate out. This explanation seems to us most in accord both with the facts observed in the field and with those obtained by experiment in the laboratory. The form of the crystals is also in accord with that of the pyrogenetic corundums. This occurrence, then, agrees well with the experiments and views of Lagorio, and is indeed an important confirmation of them.[2]

Character of the sapphires.—The sapphires occur in good-sized and generally well-formed crystals embedded in the rock and sometimes showing a slight blackish crust. At my request a complete crystallographic study of these crystals has been made by Dr. J. H. Pratt, on materials kindly furnished for the purpose by Mr. G. F. Kunz, of the firm of Tiffany & Co., of New York. From the result of Dr. Pratt's study, which has been published elsewhere,[3] the following is extracted:

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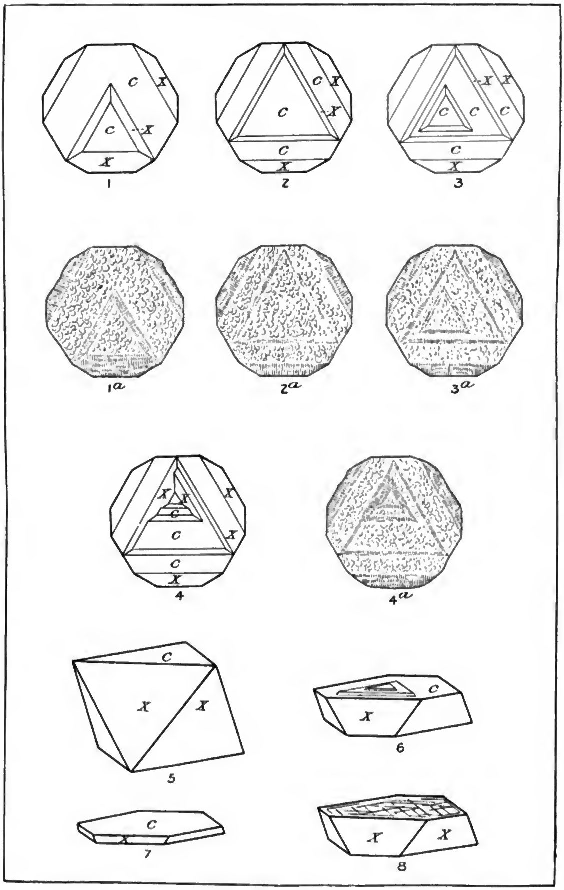
[1] Geology of Castle Mountain: Bull. U. S. Geol. Survey No. 139, p. 72.

[2] Since the above was written a large number of investigations have been published on the occurrence of corundum as a primary constituent of igneous rocks, and it is, indeed, now well recognized that this is the chief way in which it occurs. *Cf.* Morozewicz, Tschermaks Mitt., Vol. XVIII, 1898; Pratt, Am. Jour. Sci., 4th series, Vol. VI, 1898, p. 49, and Vol. VIII, 1899, p. 227; Miller, Rept. Bureau of Mines, Ontario, 1899, p. 205; Coleman, ibid., p. 250.

[3] Am. Jour. Sci., 4th series, Vol. IV, 1897, p. 424.



SAPPHIRES OF YOGO.

The sapphire crystals are etched and striated to such a degree that no crystallographic measurements were possible on the reflecting goniometer; but sufficiently accurate angles could be obtained with the contact goniometer to allow of the identification of the faces.

The prism of the second order *a* (11$\bar{2}$0), which is so common on corundum, was not observed on any of the crystals from this locality. The only two faces that could be identified were the base *c* (0001) and the rhombohedron *x* (30$\bar{3}$2), which is a new face for corundum. On one crystal two very small faces were observed, which were too small to be measured with the contact goniometer, but were probably the faces of a pyramid of the second order.

In determining the rhombohedron, ten or more independent measurements were made of $c \wedge x$. These varied from 66° to 68°, but approximated closely to 67°, which agrees very well with the calculated value, 67° 3′, for $0001 \wedge 30\bar{3}2$.

The crystals are developed as shown in figs. [5, 6, and 7, Pl. LXXVII], the prevailing type being like fig. [7]. The crystals vary from those where the base is very largely developed, having a diameter of 8 mm., while the rhombohedron is only 1 mm., to those that have the base and rhombohedron equally developed [fig. 5]. Where the faces are more equally developed, the rhombohedral faces are generally rounded.

The basal plane often shows characteristic striations which are parallel to the three intersections of the base *c* and the rhombohedron *x*, as shown in fig. [8]. These lines are sharp and distinct and on the very flat crystals can easily be measured, when examined under the microscope. The rhombohedral faces are very roughly striated without showing any distinct parallel lines.

One very common development of these crystals is a repeated growth on the basal plane, of the rombohedron *x* (30$\bar{3}$2) and the base *c* (0001), as represented in fig. [6]. These growths are very varied, as is shown in figs. [1–4], where they are drawn in basal projection. In fig. [1] there is but one secondary rhombohedron and base, which has one of its rhombohedron faces a continuation of one of the rhombohedron faces of the crystal. Fig. [2] represents a repeated growth, each face of which is entirely distinct from the faces of the main crystal. In fig. [3] there are represented two and in fig. [4] a series of such growths, where a number of the rhombohedral faces coincide. These growths occur most frequently on the flat crystals. The thickness of the rhombohedron rarely reaches 1 mm., and often they are so thin that they appear like striations. Figs. [1*a*–4*a*], representing the same crystals as figs. [1–4], have been drawn as they appear under the lens, which brings out the relation of the base and rhombohedron to better advantage.

Bauer,[1] in a recent article entitled "Ueber das Vorkommen der Rubine in Birma," has described this same style of development as occurring on the Burma rubies, but it is not so general as on the Montana corundums.

Etching figures.—The etching figures, which were observed on nearly all the crystals examined, were on the basal plane. The figures are very perfect, and, although showing many different forms, they all have a rhombohedral symmetry. Fig. [76, *a*, p. 556], represents the common etching figure, which is a rhombohedral depression terminating in a point. The edges of the depression are sharp and well defined, as are also the intersections of the rhombohedral faces of the depression. These rhombohedral faces were smooth and gave fair reflections of the signal on the reflecting goniometer. In measuring them all the crystal but the depression to be measured was covered with a thin coating of wax. Two different crystals were measured which gave for rhombohedron on rhombohedron 22° 30′; this corresponds to the rhombohedron 1017, for which the calculated value is 21° 50′. The same style of figures were observed whose edges were parallel to those of the negative rhombohedron; these, however, are not common in isolated figures.

Another common form is represented in [*c* and *e*, fig. 76], where the depression is bounded by the basal plane, which at times is so large that the rhombohedral plane is hardly visible. Fig. [76, *b*] represents etching figures, where, on the basal plane of a shallow depression, there is another and sometimes two other etching figures. These second etching figures are like the common ones shown in [*a*]. The outer rhombohedral contour of these figures is generally rounded; this is also usually the case with the deeper depressions.

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[1] Neues Jahrbuch für Min., Geol., und Pal., II, 1896, p. 209.

Often the etching figures are intergrown [*d*], and when many of these occur together they have the appearance of raised figures rather than of depressions. This raised appearance is very striking when there is a combination of the plus and minus rhombohedron in parallel position and without overlapping each other [*f*].

The figures vary considerably in size, but most of them are near 1 mm. in diameter. A few were observed that were nearly 2 mm. in diameter.

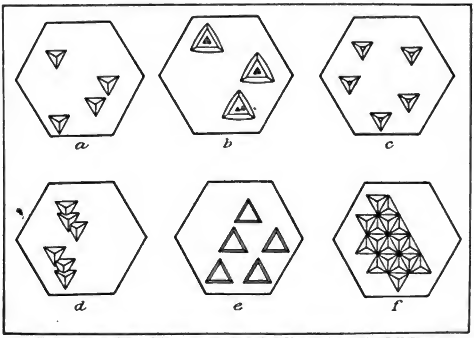

Fig. 76.—Natural etched figures on sapphires from Yogo Gulch. After J. H. Pratt.

THE EFFUSIVE ROCKS.

BASALT.

So far as is known, there are only two occurrences of effusive rocks or lavas in the Little Belt Mountains, and both of these are basalt. One is the mass resting on Cambrian beds at the head of Kinney Creek and shown on the map; the other is on the summit of Smoky Mountain, in the southern part of the area shown on the map and crossed by the line of 110° 45′. Such lava flows grow more abundant in the valley between the Little Belt Mountains and Castle Mountain, and their geological relation and petrographic character have been described.[1]

From both localities the rocks are very dark stone gray in color. The Kinney Creek occurrence is somewhat vesicular with small steam pores; both are very dense and compact, and as phenocrysts exhibit only a dull orange-colored mineral that is altered olivine.

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[1] Weed and Pirsson, Geology of Castle Mountain mining district: Bull. U. S. Geol. Survey No. 139, pp. 71-73, 129-131.

Under the microscope they are seen to be of a common type of fine-grained basalts; the groundmass, an intermingled mass of grains of iron ore and of pyroxene mingled with plagioclase feldspars, having a more or less pronounced lath-shaped development. In this lie rare phenocrysts of augite and great numbers of olivines, some of which are altered entirely to a fibrous orange-brown mineral; others contain still unaltered cores of olivine. This alteration mineral is very probably the same as that described by Iddings[1] and more lately discussed by Lawson,[2] and named by him iddingsite; at least the completely altered mineral appears to have the characters ascribed to that mineral by Lawson.

These lava flows appear to be the extrusions from dikes reaching to the surface, and it is probable that the dikes are of lamprophyric character and that these flows and their feeding dikes are of the same age and character as those occurring at Castle Mountain, whose origin has already been discussed.[3]

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[1] Geology of the Eureka District: Mon. U. S. Geol. Survey, Vol. XX, Appendix B, p. 388.

[2] Bull. Dept. Geol. Univ. California, Vol. I, p. 30.

[3] Bull. U. S. Geol. Survey No. 139, 1896, pp. 131 and 142.

CHAPTER V.

GENERAL PETROLOGY OF THE LITTLE BELT MOUNTAINS.

INTRODUCTION.

The igneous rocks of the Little Belt Mountains, taken as a whole, are of quite acid types. If the volumes of the various laccoliths, sheets, and dikes, as revealed by the study of their field relations, be taken together—that is, if they were melted down into one mass—it is clearly evident that the total amount of basic rocks, the sheets and dikes of minette, and other lamprophyric rocks, would exercise almost no appreciable influence on the composition of the whole; and even if the diorite of Neihart and the shonkinite and monzonite of Yogo Peak were added, the composition of the mass would still be an acid one.

The same has also been shown to be true of the neighboring eruptive district to the southward, that of Castle Mountain.[1]

It is the belief of the writer that in this case the average composition of the magma would be about that of a moderately acid syenite rather rich in lime and magnesia, and thus approaching an acid monzonite in character. Unlike the Castle Mountain area, however, the Little Belt area, as may be seen from the geologic map, does not represent a single important center of eruption, but a considerable number of separate centers. In these the magma has appeared chiefly in the form of laccoliths, attended by numerous sheets and dikes.

It is possible that there was once a considerable amount of extrusive material, flows, and breccias in the district, but if so, they have been entirely removed by erosion, which has progressed so far that some of the deeper-lying laccoliths are now almost bared.

Yogo Peak, however, is the only eruptive mass which, by its character and relation to the sedimentary beds in which it is placed, suggests that it may have been the outlet of igneous material to a former upper surface. It thus seems on the whole more probable that extrusive material in this district was of comparatively limited occurrence, if indeed any existed. On the whole, therefore, in discussing the character of the magmas it does not seem unreasonable to regard the character and amounts of the material now existent as representing rather closely the sum total of the products of igneous activity in this district without serious loss by erosion. If this is admitted, the general magma of the district must have been, as stated above, of a rather acid type.

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[1] Castle Mountain mining district: Bull. U. S. Geol. Survey No. 139, 1896, p. 139.

ROCKS OF THE LACCOLITHS.

There is a somewhat striking similarity in the general character of the rocks of the larger laccoliths. This is due not alone to their chemical composition, but also very largely to their texture and porphyritic nature. Comparing the analyses of the laccoliths whose rocks have been analyzed, we see that while there is a general similarity of type in the composition and that they may be so arranged as to show a gradation, in which, with decrease of silica, the lime, iron, and magnesia steadily increase, there is considerable difference between the first and last terms of the series.

Composition of laccoliths.

Constituent.	I.	II.	III.	IV.	V.	VI.
SiO_2	69.7	68.6	67.4	67.0	65.0	62.1
Al_2O_3	15.0	16.1	15.8	15.3	15.4	15.8
Fe_2O_3	.8	2.2	1.6	1.7	2.0	1.8
FeO	.3	.4	.8	1.1	1.6	2.4
MgO	.7	.7	1.4	1.8	2.6	3.6
CaO	2.1	1.4	2.4	2.2	3.1	4.1
Na_2O	3.4	4.4	4.1	4.1	4.3	3.9
K_2O	4.4	4.9	4.9	5.1	3.9	3.9

I. Granite-porphyry, Wolf Butte laccolith.
II. Granite-porphyry, Barker Mountain laccolith.
III. Granite-porphyry, Thunder Mountain laccolith.
IV. Granite syenite-porphyry, Big Baldy Mountain laccolith.
V. Diorite-syenite-porphyry, Sheep Mountain laccolith.
VI. Diorite-porphyry, Steamboat Mountain laccolith.

From the standpoint of the chemical classification of magmas the variation is sufficient to throw them into different rock groups, as has been done in this work. This difference in the chemical composition of the magmas shows itself most clearly in the mineral components, where, beginning with the most acid type, the alkali feldspars diminish, plagioclase increases, and with its increase the amount of quartz finally falls off.

Constituent.	I.	II.	III.
SiO_2	69.7	62.1	66.8
Al_2O_3	15.0	15.8	15.5
Fe_2O_3	.8	1.8	1.7
FeO	.3	2.4	1.4
MgO	.7	3.6	1.8
CaO	2.1	4.1	2.5
Na_2O	3.4	3.9	4.0
K_2O	4.4	3.9	4.5

I. Most acid of laccoliths.
II. Most basic of laccoliths.
III. Average of the six analyzed.

The average composition of the magmas taken together shows, as stated above, that it is of an acid syenite nature, standing at the extreme upper limit of this group and overlapping the granites. It is also not of an alkaline type, but tends toward the granito-diorite series, and has thus a banatite or monzonite-like character.

MINERAL COMPOSITION OF LACCOLITHS.

It is of interest to compare the laccoliths according to their mineral composition, as has been done in the annexed table:

Table of mineral components of laccoliths.

Component.	I.	II.	III.	IV.	V.	VI.
Magnetite	1.1	1.4	2.4	2.4	3.0	2.5
Biotite	3.0	4.6	2.0	3.2	7.7	8.7
Hornblende	....	3.0	3.5	4.8	6.2	11.5
Plagioclase	17.1	25.6	28.9	22.2	33.2	39.5
Orthoclase	37.5	36.2	42.8	47.0	29.0	21.0
Quartz	30.2	25.2	20.4	19.4	20.9	16.0

I. Granite-porphyry, Wolf Butte.
II. Granite-porphyry, Barker Mountain.
III. Granite-porphyry, Thunder Mountain.
IV. Granite-syenite-porphyry, Big Baldy Mountain.
V. Syenite-diorite-porphyry, Sheep Mountain.
VI. Diorite-porphyry, Steamboat Mountain.

It must be confessed that on the basis of this comparative table alone the classification of No. III as a granite-porphyry and of No. IV as a granite-syenite-porphyry seems hardly justified; that whatever one may be, the other is the same; but in this case it is not absolutely the mineral composition alone which has been taken into account, but to some extent the structure, associations, etc., and these appear to justify the division thus made.

STRUCTURE AND CLASSIFICATION OF THE LACCOLITHIC ROCKS.

It is very interesting to observe how pertinaciously the well-defined porphyritic structure clings to these occurrences of acid laccolithic rocks, and this is true not alone here, but nearly everywhere in the Rocky Mountain region. Cross has shown its occurrence in the various mountain groups of the Colorado, Arizona, and Utah region,[1] while its occurrence elsewhere in the Montana region has been shown in the earlier petrographic descriptions of Lindgren,[2] and more recently by Mr. Weed and the writer.[3] Thus, in the Little Belt, the Castle, the Moccasin, the Judith, the Little Rocky, and the Bearpaw mountains and the Sweet Grass Hills, this type is constantly found as the characteristic rock structure of the laccoliths and laccolithic masses of acid rocks occurring in these mountain groups. The rocks range from acid alkaline types with little free silica through increasing silica to very acid ones, and from these again into rocks low in free silica but containing considerable lime and magnesia. The intermediate position occupied by many of the rock types in these mountain groups is shown in the discussion of the rocks of the Judith Mountains.[4]

That this porphyritic type of structure is due to magmas of a certain chemical type—that is, of acid feldspathic nature—being intruded under laccolithic conditions, and is not generally true of all magmas intruded as laccoliths, is well shown in the Highwood Mountains,[5] where Square Butte and other laccoliths composed of rocks whose magmas are of medium (56 per cent of SiO_2) to basic character have solidified with typical granular, nonporphyritic structure.

The rocks of the laccoliths which have been described are typical granite-, syenite-, and diorite-porphyries, with many connecting types; under the system of classification urged by Rosenbusch they are typical examples of granitic porphyritic dike rocks. It is to be noted, however, that in this Rocky Mountain region dikes of this type, from both a geologic and a petrographic standpoint, play but an insignificant rôle when compared with the vast masses and importance of the great laccoliths. Certainly one who from his experience in this region would propose a classification based on method of geologic occurrence would never dream of referring these rocks to a "dike rock" subdivision, but would be far more likely to refer the acidic porphyries occurring in dikes and sheets to a division of "laccolithic rocks," the attendant, satellite-like attitude of the dikes and sheets toward these great laccoliths, from whose parent supply their material has been so often drawn, favoring this idea all the more strongly. But the very facts mentioned above show that geologic position and structure can not be taken as analogous, and that in considering them chemical composition must also be taken into account.

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[1] Laccolithic mountain groups: Fourteenth Ann. Rept. U. S. Geol. Survey, Part II, 1895, p. 165.

[2] Eruptive rocks of Montana: Tenth Census U. S., Vol. XV, p. 719; Proc. California Acad. Nat. Sci., Vol. III, 1890, p. 29; Am. Jour. Sci., 3d series, Vol. XLV, 1893, p. 286.

[3] Am. Jour. Sci., 3d series, Vol. L, 1895, p. 309; 4th series, Vol. I, 1896, p. 283; Jour. Geol., Vol. IV, 1896, p. 399.

[4] Geology of the Judith Mountains: Eighteenth Ann. Rept. U. S. Geol. Survey, Part III, 1898, p. 563.

[5] Weed and Pirsson, Highwood Mountains of Montana: Bull. Geol. Soc. America, Vol. VI, 1895, p. 400.

The fact, observed by Cross[1] in the Plateau region and by the writer[2] in many Montana areas, that many of the phenocrysts of these porphyritic laccolithic rocks were not brought up from greater depths, but were formed where they now are, finds full confirmation also in the Little Belt occurrences. The distribution of the phenocrysts is often a local phenomenon. They may be very abundant in some parts of the mass and very sparse or wanting or of different character in other parts. They may be abundant in the central portion and perhaps wholly wanting in the contact zone. They may be abundant in the main laccolith and wanting in the contemporary satellite dikes and sheets. And microscopically some of them may include all the other rock constituents, or they may, while growing, have excluded and arranged them. All such facts point clearly to their formation in the place where they now are, and tend to confirm the view held by Zirkel[3] in his discussion of this subject.[4]

DIFFERENTIATION IN THE LACCOLITHS.

No differentiation of any perceptible kind has been noted in these laccoliths; they appear to be, so far as can be told from the exposures—and in some cases they have been quite deeply dissected—entirely homogeneous both in mineral composition and in structure. They thus differ most markedly from the laccoliths of the Highwood[5] Mountains, which have such a different composition both in minerals and in structure, and also from those of the neighboring Judith Mountains,[6] where a certain amount of laccolithic differentiation is clearly indicated.

There is no evident reason which at once suggests itself why differentiation has not taken place in these Little Belt laccoliths, but since they are all of quite acid and of rather simple composition, this, combined with a certain viscosity at the time of their entrance into the sediments, has probably been the means of preventing such differentiation.

RELATION OF ROCK STRUCTURE TO DEPTH.

Here in the Little Belt, as in the other mountain groups of laccolithic character in the Rocky Mountain region, the depths at which the magmas are intruded appear to have exerted no preceptible influence on their granularity. These great masses intruded in the shaly beds of the Cambrian and bearing above them the enormous load of all the later sediments of the region are fine-grained porphyritic rocks, while their intrusive sheets at much higher horizons have the same structure and may even be quite typical granular rocks, as in the case of the nephelite- (analcite-) syenite of Otter Creek intruded in Cretaceous sediments. This shows how important a factor chemical composition is in rock structures.[1]

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[1] Laccolithic mountain groups: Fourteenth Ann. Rept. U. S. Geol. Survey, Part II, 1895, p. 231.

[2] Phenocrysts of intrusive igneous rocks: Am. Jour. Sci., 4th series, Vol. VII, 1899, p. 271.

[3] Lehrbuch der Petrographie, 3d ed., Vol. I, 1893, p. 737.

[4] See Am. Jour. Sci., 4th series, Vol. VII, 1899, p. 271.

[5] Highwood Mountains: Bull. Geol. Soc. America, Vol. VI, 1895, p. 400.

[6] Geology of the Judith Mountains: Eighteenth Ann. Rept. U. S. Geol. Survey, Part III, 1898, p. 572.

ROCKS OF THE STOCKS AND MASSIVES.

From the standpoint of theoretic petrography the granular rocks of the Little Belt Mountains occurring in intrusive stocks and masses, aside from that of Yogo Peak, do not offer any individual features which are of especial importance. The syenite of Barker has a certain interest from the possibility that it may represent the source or center from which various masses around it may have come, which idea is favored by its position and granular structure. The Pinto diorite of Neihart is interesting chiefly for the evidences of dynamic shearing which it shows, its geologic age, and its connection with the mining industries. The augite-syenite of Belt Creek and the nephelite- (analcite-) syenite of Otter Creek are important from their petrographic character but not from any direct relationship with other igneous rocks, as they are isolated and not a portion of a complex, and therefore there is no direct connection between them and other masses. The chief interest of this kind centers at Yogo Peak, where, as was shown in the former paper on that area, there is a progressive change in rock types, so that one passes from an acid syenite over continuous rock masses through the monzonite stage into shonkinite—a very basic rock.

If one, however, as may be seen by referring to the geologic map and to the full description of the peak by Mr. Weed, takes the Yogo Peak mass as simply the westward extension of the greater intrusive stock which stretches some 4 miles more to the eastward, it will be seen that in this direction the syenite (banatite) of Yogo Peak passes into a still more acid stage, that of the syenitic granite-porphyry of Yogo Peak type previously described. As one passes on to the eastward this gives way to syenite-porphyry and then to another occurrence of shonkinite, which forms the boundary against the sediments at the head of Running Wolf Creek. Thus the geologic position of the syenitic rocks and the shonkinite masses is a peripheral one with respect to the more acid granite-porphyry and to each other, precisely the position demanded by that view of theoretic petrology which regards differentiation in rock masses as produced by the accumulation of basic material at the outer walls of the inclosing chamber, with the more acid material within. In strict accord with the theory one would expect the whole outer margin of this mass to be composed of syenitic rocks encircled by shonkinite; it is indeed possible that this is so, but it could not be definitely determined in the field, partly on account of the nature of the ground, from which the exposures were either inaccessible or covered by talus slides and débris, and partly from lack of time to devote to a long and minute research.

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[1] Cross, Laccolithic mountain groups: Fourteenth Ann. Rept. U. S. Geol. Survey, Part II, 1895, p. 230. See also Geology Judith Mountains: Eighteenth Ann. Rept. U. S. Geol. Survey, Part III, 1898, p. 574.

There seems, however, to be sufficient facts at hand, not only to show that the Yogo Peak mass and its eastward extension are an example of differentiation in place, but to add certain facts concerning such occurrences. This is shown in fig. 77, B, which is a little sketch map of the area. In A is shown, in ground plan—that is, in horizontal section—the theoretical disposition that an originally homogeneous magma would assume on cooling, the more basic portions differentiating toward the margins. It is very clear that, the rate of cooling being most rapid proportionately along the sides, the greatest amount of differentiated material would be found at the ends of the cavity; it would be very thin along the sides, and might even be wanting. Even if one considers differentiation to be a process of fractional crystallization, as has been suggested by Harker[1] and elaborated by Becker[2], the result would be the same. A familiar example would be the filling up of the corners of a vessel containing a crystallizing saline solution and leaving a rounded cavity in the center, which contains the mother liquor. The figure given shows the ground plan of the cavity. The vertical extension is not here considered. It is of the nature of a very broad, thick dike. The Yogo Peak mass, as shown in the sketch map, has approximately this general form and arrangement of material, and is from half a mile to a mile in width and several miles in length, and hence could hardly be called a dike. Yogo Peak proper is a somewhat bulbed extension, and it is here that the differentiation of the magma is seen to best advantage, and has been already briefly described.[3] The various types, passing from the granite-porphyry southwest along the peak, gradually merge into one another along the exposures, and one passes from the granite-porphyry into syenite (banatite), then into monzonite, and finally into shonkinite. This is shown very strikingly by the comparison

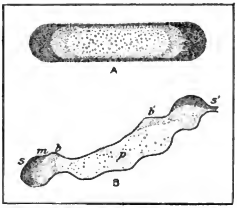

FIG. 77.—Diagram to show differentiation at Yogo Peak.

A, theoretical arrangement of differentiated mass, acid center, basic periphery (horizontal plan); *B*, sketch map of Yogo Peak mass and extension; *s*, shonkinite; *m*, monzonite; *b′*, banatite (syenite); *p*, granite-porphyry; *b′*, syenite-porphyry; *s′*, shonkinite; *smb*, Yogo Peak mass; *p*, plateau extension; *b′*, Storr Peak; *s′*, peak head of Running Wolf Creek.

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[1] Quart. Jour. Geol. Soc., Vol. L, 1894, p. 327.

[2] Am. Jour. Sci., 4th series, Vol. IV, 1897, p. 257.

[3] Weed and Pirsson, Igneous rocks of Yogo Peak: Am. Jour. Sci., 3d series, Vol. L, 1895, p. 467. See also the full account given by Mr. Weed in the preceding portion of this work.

of the chemical analyses of the types involved. Fine fresh material of the granite-porphyry suitable for analysis and equal in quality to the other rocks was not obtained, and therefore an analysis of the granite-porphyry of Thunder Mountain is selected in its place, as the two rocks must be very close together in their chemical composition, as shown by the study of thin sections. The Thunder Mountain rock has possibly not quite so much free quartz, and hence a little lower content of silica, but for our purpose such small differences as must exist may be practically disregarded, since they could have no effect upon the general result.

Composition of the rocks of Yogo Peak, Montana.

Constituent.	I.	II.	III.	IV.	I*a*.	II*a*.	III*a*.	IV*a*.
SiO_2	67.4	61.7	54.4	49.0	1.124	1.027	0.907	0.813
Al_2O_3	15.8	15.1	14.3	12.3	.153	.145	.139	.119
Fe_2O_3	1.6	2.0	3.3	2.9	.010	.013	.021	.018
FeO.........	.8	2.3	4.1	5.8	.012	.031	.057	.080
MgO	1.4	3.7	6.1	9.2	.035	.092	.152	.229
CaO	2.4	4.6	7.7	9.7	.043	.082	.139	.173
Na_2O........	4.1	4.4	3.4	2.2	.066	.070	.055	.036
K_2O........	4.9	4.5	4.2	4.9	.052	.048	.045	.052

I. Granite-porphyry.
II. Syenite (banatite).
III. Monzonite.
IV. Shonkinite.
I*a*—IV*a*.—Molecular oxides of preceding.

At the east end there are no such excellent outcrops to furnish material for investigation and analysis as at Yogo Peak proper. The change is from the granite-porphyry to a more basic syenitic phase, with very little quartz and predominant orthoclase. This is characterized by a corresponding change in microstructure, the sections of the rock at Storr Peak, where good material is seen in the outcrops, showing, as previously described, a rock that is already nearly out of the porphyritic stage and almost a fully granular one. In the hand specimen it appears wholly rather fine granular; the minute amount of groundmass is seen only under the microscope.

Still farther to the eastward, where good fresh material is found again, it is the coarser-grained shonkinite, with typical granitoid structure. Thus, as so commonly is the case, chemical composition and structure are directly related, and this is shown at both ends of the mass. The tendency of the very acid magmas to form porphyritic rocks under the same conditions where the basic ones form granular types, is here well exemplified; and although one expects the center of a mass to possess conditions more favorable for a higher degree of granularity than the periphery, this is manifestly offset in the case under consideration by the elongated form of the mass, which in a great degree exposes its whole content to more nearly equal conditions, and thus we find granite-porphyry (with, however, very coarse groundmass) and the coarse-grained shonkinite united in the same mass.

As the theoretical diagram of fig. 77 would indicate, one would expect more basic material in slight amount to occur along the sides of the mass. It may indeed do so, but this point the author is unable to decide from personal observations, for the reasons given above, but it can at least be said that if it does occur it is small and of no importance, except from the theoretical point of view.

A modification of the foregoing theory for the arrangement of the several parts of the Yogo stock might be suggested as follows: If a body of magma had been pressed upward into a cavity opened for it in the crust, and had then remained for a period at rest, it might have differentiated, as required by theory, into a more basic outer envelope, passing into more and more acid material within. If at this time the present opening which the Yogo stock now occupies had formed, with a forcing upward of the differentiated material at the same time, the acid inner portion might have been driven through the more basic envelope, crowding it back into the ends of the great fracture and itself occupying the inner part. It is thought, however, that the greater part of the differentiation has occurred after the material came to rest, or at least very nearly so, and that movements after the main injection have been slight, otherwise the orderly arrangement of the parts, taken as a whole, would have been disturbed, with a consequent large amount of mixing.

FORMATION OF THE APLITIC DIKELETS.

The numerous little syenite-aplite dikelets or veins which cut the Yogo rocks in all directions, previously described, are readily explained by the following hypothesis: As the upper and outer masses of the stock crystallized into rock and cooled they contracted and were broken into innumerable blocks, like all igneous rocks. The heavy masses, resting on the still molten, unconsolidated, acid, inner, lower portion, by their weight gradually forced it up into these fractures, where it solidified as the dikelets. That the material was forced into the fracture planes of the rocks while they were still very hot is shown by the granular character from wall to wall without sign of contact influence, and by the fact that such very narrow dikelets are really granular crystalline and not glassy or microcrystalline. The fracture planes would also serve as channel ways for escaping vapors from below and from the walls, and these would tend to make the magma of the little dikes extremely fluid and enable it to penetrate the narrowest cracks.

DIFFERENTIATION.

Throughout this report this term is used to denote simply the cleaving of an igneous magma into two or more of different composition; it does not denote any theory as to the process by which it is accomplished. That differentiation occurs the author regards as long since demonstrated. The process that causes it, whether molecular flow, convection currents, fractional crystallization, or other of the various theories suggested, remains to be discovered.

VARIATION IN MINERAL COMPOSITION.

The character of the progressive variation in the rocks of Yogo Peak is shown very clearly by the study of the table of analyses, with their oxides, which has just been presented. These exhibit many features of interest when studied in comparison with the mineral composition and position of occurrence. Thus with respect to the mutual relations of lime and magnesia, the table shows that in molecular proportions, from granite-porphyry to shonkinite, they run as follows:

Molecular proportions of lime and magnesia in rocks of Yogo Peak, Montana.

Constituent.	Granite-porphyry.	Syenite (banatite).	Monzonite.	Shonkinite.
MgO	35	92	152	229
CaO	43	82	139	173

Thus in the granite-porphyry the lime is greater than the magnesia; in the shonkinite, the reverse. This shows itself clearly in the mineral products formed from the magmas. In the granite-porphyry there are hornblende and plagioclase. The surplus of lime controls and shows itself in the feldspar. Then, as the relative amount of magnesia increases, the latter begins to control; more of the lime is taken up by it, and augite begins to appear and the plagioclase to diminish. Finally, in the shonkinite, where the magnesia is considerably in the lead, hornblende in its ratio to pyroxene almost disappears, and the magnesia takes the lime into augite before the plagioclase commences to form. Therefore, in the most basic type it is entirely wanting and we see the surplus of magnesia forming olivine, or in combination with potash and alumina producing biotite. These relations are also shown in the following table of mineral components, in which, however, the most basic type of the shonkinite is not represented, on account of the lack of its analysis:

Table showing mineral components of rocks of Yogo Peak, Montana.

Component.	Granite-porphyry.	Banatite.	Monzonite.	Shonkinite.
Iron ore	2.4	3.1	5.1	1.0
Biotite	2.0	.9	12.1	18.0
Hornblende	3.5	12.0	4.5	4.0
Pyroxene		5.4	20.7	35.0
Olivine				7.0
Plagioclase	28.9	29.5	27.2	10.0
Orthoclase	42.8	42.5	30.4	25.0
Quartz	20.4	6.0		

They can be even more strikingly represented by a series of diagrammatic curves, as shown in fig. 78. In this equal distances have been taken as abscissas, and on the perpendiculars erected the amounts of each mineral have been set off as ordinates, and through these points the curves have been drawn. The diagram shows several features of interest. Thus the pyroxene, determined by three points, is absolutely a straight line. The quartz, determined by two points only, is also drawn as a straight line. The olivine, for which one point only exists, is of course purely diagrammatic. The curves between points can not, of course, be very exact, but they are sufficiently so for this purpose. There is an interesting mutual relation between hornblende and biotite; they appear to complement each other. The preponderance of orthoclase over plagioclase in the more acid rocks—the granite-porphyries, passing into the syenites (banatites)—is practically lost in the monzonite and then suddenly acquired again in the basic types. In the more basic shonkinite, lying to the right of the diagram, it is clear that hornblende, iron ore, and plagioclase would be wanting, which is, indeed, the actual fact.

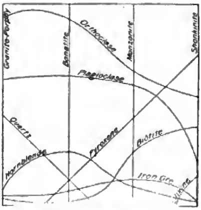

FIG. 78.—Variations of minerals in rocks of Yogo Peak.

It is clear, also, not only that the diagram thus constructed represents the mineral variation at Yogo Peak, but that by means of it we may obtain the mineral composition of any of the intermediate products of the mass by erecting at a suitable point a perpendicular parallel to those already drawn. Then the points at which it is intersected by the curves, measured from the foot with a millimeter scale, give directly the proportions by weight of the minerals for the intermediate rock type.

The proper method to have constructed this diagram, with correct abscissas, would have been to have measured along a line from the granite-porphyry to the shonkinite boundary in the field, and, noting the distances at which the types taken for analysis occurred, they would have furnished correct data for the abscissas. Then to ascertain the mineral composition of the rock mass at any point it would only be necessary to measure from there to the nearest point where the composition is known from the analyses, and, erecting a perpendicular at a corresponding point on the diagram, the curves would give the mineral composition.

CHAPTER VI.

DISCUSSION OF MAGMAS BY GRAPHIC METHODS, AND ABSORPTION OF SEDIMENTS BY MAGMAS.

DISCUSSION OF MAGMAS BY GRAPHIC METHODS.

The introduction of graphic methods for the study and comparison of groups of related rock analyses we owe to Iddings,[1] and more recently[2] to Becke,[3] Michel Lévy,[4] and Brögger.[5] These methods have had the advantage of presenting more directly to the eye the facts furnished by the analyses, and thus they permit a more direct comparison of the compositions of the rocks with each other than can be made from the table of figures giving the several amounts of the rock-making oxides in molecular proportions. This is more especially true of the diagrams of Michel Lévy and of Brögger. The diagrams of Iddings, on the other hand, do not serve so well in this direction, but are more useful in showing the mutual relations produced by processes of differentiation and the direction in which the oxides tend during such processes. These methods, then, may be said to represent pictorially the analysis and to make its results more easily grasped, especially by those who are not chemists and to whom the numerical results of analytical work do not readily appeal.

It has always seemed to the writer, however, that the results so far obtained by these methods have been inadequate. They permit of comparison, it is true, but what has resulted from the comparisons of the diagrams would mainly have resulted from comparison of the analyses themselves. It would seem that the analyses are mathematical data, which, if we knew how to use them rightly, should enable us to place the subject of differentiation or the derivation of magmas from one another on a more mathematical basis, and thus to gain a better statement of the laws governing these processes, and by analogy to suggest new ideas.

Efforts tending in this direction by use of the graphic method have been made by Iddings[6] and some very interesting data obtained. On the mathematical side Brögger[7] also has given some very remarkable data showing that the varied magmas of the south Norway region can be derived by the admixture of parent magmas in proper quantities, and these latter, which represent types actually occurrent in the district, may themselves be derived from simpler forms. When one considers the large number of variables in the magmas, these agreements furnish one of the most powerful and logical arguments against the contention of those who see no connection between the distribution and the chemical composition of igneous rocks and relegate the whole affair to chance and chaos. In the original diagrams of Iddings[1] and in succeeding ones by Washington,[2] Dakyns and Teall,[3] and Harker[4] the molecular ratios of the silica are made to serve as abscissas, while those of the metals are taken as ordinates. Supposedly the reason for this selection is that the silica is the only acid present, the metals being the bases.

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[1] Origin of igneous rocks: Bull. Philos. Soc. Washington, Vol. XII, 1892, pp. 89-214.

[2] In revising the proof the author takes the opportunity to mention also the elaborate and beautiful diagrams of Loewinson-Lessing, which have just been received, in his work Studien über Eruptivgesteine Compt. Rend. 7th Cong. Geol. Internat., 1899. p. 193.

[3] Tscher. Mitt., Vol. XVI, 1896, p. 308.

[4] Bull. Soc. Géol. France, 3d series, Vol. XXV, 1897, p. 326.

[5] Ganggefolge des Laurdalits, p. 255, Videnskab. Skrift I, Math.-nat. Kl. 1897, No. 6.

[6] Jour. Geol., Vol. III, 1895, p. 957.

[7] Ganggefolge des Laurdalits, 1898, p. 276.

It has appeared to the writer, however, that the silica, being a variant and closely connected with the other oxides, should also be used as an ordinate in any scheme which should graphically represent the variations in the magmas of a given unit district. The difficulty arises that there seems to be no definite basis on which to select abscissas. We might, for example, select the relative volumes of the various rocks, but these are rarely even approximately known. An attempt in this direction has been made, however, with the Yogo Peak rocks, with the effect of furnishing some results which are not only very interesting, but even surprising.

For this purpose equal distances of 2 centimeters have been arbitrarily selected as abscissas, and at the points *a*, *b*, *c*, and *d* of the accompanying diagram (fig. 79) perpendiculars have been erected. The reason for thus arbitrarily selecting these equal distances is the same as that previously given in the explanation of the diagram of mineral variation at Yogo Peak (fig. 78), because they represent in a general way those relations seen in the field. On the perpendiculars thus erected distances in millimeters have been measured off corresponding to the molecular relation of the oxides as shown by the analyses of the Yogo Peak rocks, the molecular ratios having been multiplied by 100 throughout for convenience. For greater accuracy, however, a scale of twice the size at which the figure is reproduced has been actually used in plotting and obtaining the results given in the following work.[5]

At *d* the molecular ratios of the shonkinite have been measured off and plotted, the silica being given twice the scale of the other oxides to condense the diagram, and this relation of the silica has been followed throughout the series of analyses, since its line does not intersect those of the other oxides. At *c* the monzonite has been similarly laid off, and at *b* the syenite (banatite). Since good material for the analysis of the granite-porphyry was not collected, the analysis of the fresh and precisely similar type of Thunder Mountain has been chosen in its place, as was done in the diagram of mineral variation, and its molecular relations have been plotted at *a*. Through the similar points thus obtained on the four perpendiculars lines have been drawn, and the resulting diagram shows the directions of molecular variation at Yogo Peak.

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[1] Loc. cit.

[2] Ægina and Methana: Jour. Geol., Vol. III, 1895, p. 160.

[3] Garabal Hill and Meall Breac: Quart. Jour. Geol. Soc., Vol. XLVIII, 1892, p. 104.

[4] Carrock Fell: Quart. Jour. Geol. Soc., Vol. LI, 1895, p. 125.

[5] In reproducing the diagram, which was plotted and drawn with great care, the cut is found to be not absolutely accurate in a vertical direction, though correct horizontally. This has occurred in the process of reproduction, and should be kept in mind in case the measurements described in the following pages are repeated.

It is of interest to study this diagram and observe the mutual relations and character of the lines or differentiation paths of the oxides. The silica, of course, does not intersect any of the others. It will be noticed at once how very nearly straight lines the alumina, silica, and ferrous iron are; the magnesia, the soda, and the potash seem to indicate very flat curves; and probably they should all be drawn as very flat curves. The approach to symmetry which the figure possesses seems to indicate that the abscissas have been taken with a fair degree of correctness, and that this is so will be shown in other ways.

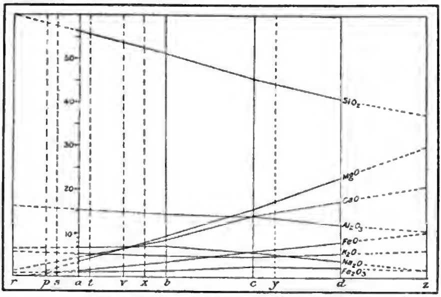

FIG. 79.—Differentiation diagram of Little Belt Mountain rocks. *a*, *b*, *c*, *d*, analyses of rocks of Yogo Peak; *a*, granite-porphyry (of Thunder Mountain); *b*, syenite (banatite); *c*, monzonite; *d*, shonkinite; *y*, minette, Sheep Creek; *x*, diorite-porphyry, Steamboat Mountain; *v*, syenite-diorite-porphyry, Bear Park; *t*, syenite-granite-aplite, Sheep Creek; *s*, granite-porphyry, Barker Mountain; *p*, granite-porphyry, Wolf Butte; *r*, rhyolite dike, Yogo Ridge; *z*, missourite.

RELATION TO OTHER MAGMAS.

On a previous page it was suggested that the mineral composition of any of the gradational types of Yogo Peak could be found from the diagram of variation there given; and so, in respect to chemical composition, the diagram of variation just described should give the chemical composition of any of the intermediate varieties. Unfortunately, having used all of the analyses to construct the figure, there are none left to directly test this, but a study of the other analyses of rocks of this region shows the striking fact that this is the diagram of variation for the igneous rocks of the Little Belt Mountains.

Thus, if at the point *y*, distance one-half centimeter from *c* and one and one-half from *d*, we erect a perpendicular to *cd*, the point where it intersects the lines of the various oxides, measured by a millimeter scale to its foot, will give the molecular ratios of a magma intermediate in type between *c* and *d*. This is shown in the following table, where the first column gives the intercepts in millimeters—that is, decimal parts of a meter, which are here considered as molecular ratios—which multiplied by the corresponding molecular weights give the percentages seen in the second column. This is the theoretical composition of a magma between *c* and *d* in composition.

Actual and theoretical composition of minette.

Constituent.	I.	II.	III.	IV.
SiO_2	.880	52.8	52.26	53.0
Al_2O_3	.135	13.9	13.96	13.8
Fe_2O_3	.020	3.2	2.76	3.2
FeO	.065	4.7	4.45	4.5
MgO	.175	7.0	8.21	6.9
CaO	.145	8.1	7.06	8.2
Na_2O	.050	3.1	2.80	3.1
K_2O	.045	4.2	3.87	4.4
X		3.0	4.88	2.9
Total		100.0	100.25	100.0

I. Measured oxides 5 mm. left of *c* in fig. 79 equals molecular ratios.
II. Above converted into percentages; $X = TiO_2, H_2O, P_2O_5$, etc., supplied by difference.
III. Actual analysis of minette of upper Sheep Creek.
IV. Three parts of monzonite and one part of shonkinite mixed.

In the third column is given the actual analysis of the minette of Sheep Creek, and it will be seen at once how close is the agreement between the two, only a few tenths of 1 per cent, except in the lime and magnesia.

It is clear from the foregoing that the minette magma *y*, considering its position between *c* and *d*, where $3yc = yd$, can be expressed in terms of *c* and *d* as follows:

$$y = \frac{3c + d}{4}$$

The solution of the equation is given in the fourth column of the adjoining table, and agrees very closely with both the theory derived by measurement of the intercepts and the actual analysis.

The Sheep Creek minette is not, however, the only magma which can be thus derived from the differentiation diagram of Yogo Peak. If at the point x, between a and b, a perpendicular be erected we can obtain in the same way the composition of the magma of the Steamboat Mountain laccolith; similarly the perpendicular v gives the rock of Bear Park, and t the narrow dike of aplite (granite-syenite-aplite) cutting the minette of Sheep Creek, which is thus so well shown to be complementary to it. The result of these comparisons is shown in the following table. The symbol X stands, as before, for the titanic and phosphoric acids, barium, manganese, water, etc.

It is also evident that the rock composing the laccolith of Big Baldy Mountain should be included in the series, since its analysis is nearly identical with that of Thunder Mountain. For this reason its calculation from the diagram has not been attempted.

Comparison of theoretical and actual magmas.

Constituent.	A^1.	A^2.	A^3.	B^1.	B^2.	B^3.	C^1.	C^2.	C^3.
SiO_2	1.050	63.0	62.18	1.080	64.8	64.95	1.110	66.6	66.29
Al_2O_3	.146	15.0	15.77	.150	15.5	15.44	.150	15.4	15.09
Fe_2O_3	.012	1.9	1.83	.013	2.1	2.02	.010	1.6	1.37
FeO	.029	2.1	2.44	.020	1.5	1.60	.016	1.1	1.17
MgO	.080	3.2	3.55	.060	2.4	2.65	.043	1.7	2.39
CaO	.075	4.2	4.13	.060	3.3	3.07	.049	2.7	2.38
Na_2O	.070	4.3	3.92	.065	4.0	4.25	.066	4.1	3.96
K_2O	.050	4.7	3.91	.050	4.7	3.87	.053	4.9	4.91
X	......	1.6	2.50	......	1.7	2.26	......	1.9	2.29
Total.	......	100.0	100.23	......	100.0	100.11	......	100.0	99.85

A^1. Molecular proportions of oxides measured at x in fig. 79.
A^2. Above converted into percentages, $X = TiO_2$, P_2O_5, etc., supplied by difference.
A^3. Actual analysis of diorite-porphyry of Steamboat Mountain laccolith.
B^1. Molecular proportions at v in diagram.
B^2. Above converted into percentages.
B^3. Actual analysis of syenite-diorite-porphyry of Bear Park.
C^1. Molecular proportions at t in diagram.
C^2. Above converted into percentages.
C^3. Analysis of syenite-granite-aplite cutting minette at head of Sheep Creek.

It will be seen from the table that the agreement between the calculated values and those found is very close. It may be said of these rocks that, given the percentage of one element, the chemical composition of any intermediate type can be deduced from the diagram.

EXTENSION OF THE DIAGRAM.

The quite regular and symmetrical character of the diagram suggests that it might be carried out by prolongation of the lines, and that perhaps other magmas, on the one hand more acid, on the other more basic, might be derived from it. The relations already shown to exist may also be true of other magmas of the district. That this is so is easily shown. Thus to the left of *a*, in fig. 79, we may extend the lines of the molecular oxides as shown by the dotted lines. They are carried out as far as *r*, which marks the limit of the diagram. The magnesia and ferrous iron have disappeared before this point is reached. If we now erect a perpendicular at *s* and measure and reduce to percentages as before, we obtain the theoretical magma shown in the column A^2 of the annexed table, while A^3 gives the actual analysis of the Barker Mountain rock. The agreement is very striking. In the same manner, perpendiculars erected at *p* and at *r* give other magmas whose relations to actual types are shown in the annexed table under B and C. The agreement is quite close on the whole, but it is to be noted that the alumina line, instead of being a straight prolongation of the *ab* section, really curves slightly downward, if we take the percentages found in the analyses as ordinates, and thus completes in its whole course a very flat, gentle curve.

Comparison of derived and actual magmas.

	A^1.	A^2.	A^3.	B^1.	B^2.	B^3.	C^1.	C^2.	C^3.	D^1.	D^2.	D^3.
SiO_2	1.150	69.0	68.60	1.165	69.9	69.68	1.200	72.0	73.12	.750	45.0	46.06
Al_2O_3....	.155	16.0	16.13	.158	16.2	14.97	.160	16.4	14.27	.105	10.8	10.01
Fe_2O_3 ...	.012	1.9	2.22	.008	1.2	.79	.005	0.8	.51	.020	3.2	3.17
FeO	.010	.7	.44	.005	.4	.34	.....	.....	.26	.105	7.5	5.61
MgO	.020	.8	.72	.013	.5	.66	.....	.....	.24	.300	12.0	14.74
CaO	.035	1.9	1.36	.030	1.7	2.10	.011	0.6	1.10	.210	11.7	10.55
Na_2O....	.065	4.0	4.37	.061	3.9	3.38	.062	3.8	3.43	.020	1.2	1.31
K_2O.....	.055	5.1	4.89	.055	5.1	4.40	.055	5.1	4.90	.062	5.8	5.14
X	.....	.6	1.64	.....	1.1	3.54	.....	1.3	2.35	.....	2.8	2.98
Total..	.....	100.0	100.37	.....	100.0	99.86	.....	100.0	100.18	.....	100.0	99.57

A^1. Molecular proportion of oxides measured at *s* in fig. 79.
A^2. Above converted into percentages. X = TiO_2, P_2O_5, H_2O., etc., by difference.
A^3. Actual analysis of granite-porphyry of Barker Mountain.
B^1. Molecular proportion of oxides at *p* in diagram.
B^2. Above converted into percentages.
B^3. Analysis of granite-porphyry of Wolf Butte.
C^1. Molecular proportion of oxides at *r* in diagram.
C^2. Above converted into percentages.
C^3. Analysis of rhyolite-porphyry dike on Yogo Ridge.
D^1. Molecular proportion of oxides at *z* in diagram.
D^2. Above converted into percentages.
D^3. Analysis of missourite of Highwood Mountains. Am. Jour. Sci., 4th series, Vol. II, 1896, p. 315.

If now, on the other hand, we extend the lines to the right—that is, in the basic direction—we may derive basic magmas and examine what the products of the differentiation in this direction might have been.

If at *z*, in which the distance *zd* equals that of *cd*, we erect a perpendicular, the intercepts on the prolonged lines are seen in D^1 of the annexed table, which yields the theoretical magma of D^2. An inspection of this magma shows at once that it is typical for a basic leucitic rock, and that this is so is shown by its general close agreement with the analysis of missourite of the Highwood Mountains,[1] a granular, intrusive augite-olivine-leucite rock, the granular plutonic representative of the leucite-basalts.

The relation thus brought out is a most interesting one. It shows that if differentiation had gone on as far beyond the shonkinite as the latter is from the monzonite there would have been formed, not a pyroxenite, but a missourite, and it shows the intimate relation between the latter and shonkinite. This relation is confirmed in fact, for the stock which furnished the original missourite has shonkinite phases.

We may thus deduce that in regions where monzonite occurs as a main stock type both shonkinite and missourite facies and dependencies are to be expected and should be carefully looked for.

It is also quite true that this deduced magma might express itself as a pyroxene-biotite rock (biotite instead of olivine and leucite), and especially if the magma crystallized under such conditions that water vapor and fluorine, necessary for the formation of biotite, could not readily escape.

The more basic type of shonkinite, described in the original paper and mentioned in this work under shonkinite, with its large and abundant poikilitic biotites, would thus in part be accounted for.

Such a rock, though of pyroxenic habit, is very different from the pyroxenites which represent the differentiation end products of the gabbro-peridotite group, as shown by its abundant potash, and is not to be confounded with them.

DEDUCTION OF RESULTS.

From the results which have been obtained in the foregoing it seems not too much to say of rocks of the Yogo series that, given the percentage of one element, the chemical composition of any rock of the series to within a fraction of 1 per cent can be deduced from the diagram. It is approximately true in practice and appears absolutely so in theory. There are a few analyses of rocks in the Little Belt Mountains given in these pages which do not fit into the diagram. One of these is that of the "Pinto" diorite of Neihart. This rock, however, was injected and formed before the Paleozoic, and the whole of that vast period elapsed before the Yogo series was produced. The magmas then can have nothing in common; all sorts of changes and alterations in magmatic conditions may have occurred during the enormous lapse of time involved in that great era. Another is the syenite of Barker, which comes very near the syenite-diorite porphyry of Bear Park. The difference lies chiefly in the relations of magnesia and alumina; these are not great, but still distinct. It is to be noted, however, that this syenite is a granular type and an independent abyssal rock. Those rocks, however, which connect geologically with the Yogo series, evidently of the same age and belonging to the some general center, and depart most clearly from the diagram, are the syenite-porphyry of Yogo Ridge and the two lamprophyres, the analcite-basalt dikes of Big Baldy and Bandbox mountains.

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[1] Am. Jour. Sci., 4th series, Vol. II, 1896, p. 321.

Why these depart from the diagram series can not be definitely explained, but the writer believes that these complementary types are rocks of secondary differentiation, since, in contrast to the view of Brögger,[1] who holds the complementary rocks in his region to have been of deep-seated origin, he believes that in many areas they are produced by laccolithic differentiation, as in the Judith Mountains.[2] In this case they belong to a later order of differentiated products than those of the Yogo Peak series, and might well differ from them.

In conclusion a few deductions can certainly be drawn from the remarkable relations which have been shown to exist in the Yogo series. The masses occur over a large area and their magmas have certain definite relations to one another, so that any one magma may be definitely and mathematically stated in terms of the others or be derived from them. It is conceivable that the differentiation lines or paths of the molecular oxides of the diagrams might be drawn as curves and these curves mathematically discussed and their equations found.

All this points clearly and unequivocally to the fact that these magmas have had a common, deep-seated origin—that they have been derived from a common source according to some definite law. It does not point toward these magmas having been produced by chance, from heterogeneous substances, or by the absorption of sediments or other material; on the contrary, it would be impossible to concede this and at the same time believe that harmonious relationships are due to the operations of natural law.

Whether the relationships and manner of discussing them which have been shown for the Yogo series can be also shown at the present time for other regions is not easy to say. The great advantage in having a series of analyses from a unit rock mass whose differentiation represents that of the region is evident, and it would seem as if this should be the point of departure in the study of other series. Some preliminary work on other regions of which groups of analyses exist seems to indicate that generally the relations are much more complex than in the Little Belt area and more difficult to unravel. This may also be due in part to the unfamiliarity of the writer with these regions and their rock types.

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[1] Eruptivgesteine des Christianiagebietes, Grorudit-Tinguait Serie, 1894, p. 152.

[2] Geology of the Judith Mountains: Eighteenth Ann. Rept. U. S. Geol. Survey, Part III, 1898, p. 572.

ABSORPTION OF SEDIMENTS BY MAGMAS.

In regard to the question which has been brought up at various times, and which is being actively debated in Europe at present by Brögger, Michel Lévy, Lacroix, and others, as to whether igneous masses are capable of dissolving and absorbing large amounts of the stratified rocks with which they come in contact, becoming changed in composition thereby, it can be said that the Little Belt area presents no facts in favor of such a view. Indeed, the only occurrence in the district which could lend any color to such a supposition is that at Yogo Peak, the change in chemical composition from center to sides being alluded to. But here again the facts speak against it. The contact metamorphism is too inconsiderable; the change in basicity at the ends of the mass and not on the sides would by this be incomprehensible, although easily explained, as previously noted, by the cooling and crystallizing of a differentiated mass; but it is especially in the comparison of the chemical composition of the different phases that such a supposition receives a final blow. A reference to the comparative table of Yogo analyses shows that the greatest increase has been in magnesia, and that a rock containing an enormous percentage of magnesia in comparison to the other elements should have been absorbed; but the difficulty is that no such rock occurs in the district. The section, as described in the foregoing pages by Mr. Weed, is known from the gneisses of the Archean upward, and consists of shales, sandstones (i. e., quartzites), and limestones, the latter containing but little iron and little magnesia compared with the lime. It is impossible on any chemical basis to account for the shonkinite as produced by the granite-porphyry having absorbed local limestones or shales. Moreover, the method of occurrence shows, as previously described, that the arrangement is local and must have been produced by local causes after the magma reached its present position. Other facts in this direction might be cited, but the above is decisive and therefore sufficient. A somewhat similar instance is found at Castle Mountain and has been described.[1] It is not intended in this statement to generalize upon other regions. It should be clearly recognized that in different areas unlike conditions have often prevailed and given rise to quite differing phenomena; and without regard to the general aspect of this question of absorption, it is only intended to show that there is no evidence in favor of it in this region.

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[1] Weed and Pirsson, Geology of Castle Mountain mining district: Bull. U. S. Geol. Survey No. 139, 1896, p. 133.

CHAPTER VII.

ANALYSES OF ROCKS.

For convenient reference the various analyses of rocks of the Little Belt Mountains which have appeared in the foregoing pages are here grouped in one table. Of these analyses, Numbers I, V, VI, X, XI, XII, XIII, XIV, XV, XVII have been made by Dr. W. F. Hillebrand, and Numbers II, III, IV, VII, VIII, IX, XVI by Dr. H. N. Stokes, in the laboratory of the United States Geological Survey. The painstaking accuracy and skill of these chemists are well known, and the contention of Hillebrand[1] for more exact and careful work in rock analysis is being more and more justified as such data are given a mathematical usage, and the graphic discussion in the foregoing pages is a direct evidence of this. No problem meets the analytical chemist requiring more skill and special training than the complete and accurate analysis of an igneous rock, and without this training and careful attention to the best modern methods even a very good analyst is liable to make serious errors. The too common method of turning rock analyses over to beginners and students is an absurdity on the face of it; more useful work on the whole would be achieved if the investigator, provided he is a chemist, made the analyses himself and turned the petrographic work over to the student. Of the vast mass of rock analyses which confront the petrographer it must be confessed that very few are of any value from a modern standpoint; the most are mere approximations, and many not even that.

Even in the handbooks prepared by masters of the science many analyses are quoted which are obviously wrong, especially in the basic rocks. A type is described as being composed chiefly of augite and often olivine, but the analysis gives but a slight amount of magnesia and a large percentage of alumina; or the iron is given as ferric acid and titanic and phosphoric acids are not determined, while loss by ignition may be largely carbon dioxide. The writer desires to emphasize these points, because in his opinion this is the greatest weakness in petrographic work. Thus, for example, in spite of the great number of occurrences which have been described, there are very few reliable detailed and accurate analyses of European nephelite and leucite basic rocks.

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[1] Jour. Am. Chem. Soc., Vol. XVI, 1894, p. 90; Bull. U. S. Geol. Survey No. 148, 1897, p. 13.

Table of analyses of rocks

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO_2	73.12	69.68	68.60	67.44	67.04	66.29	64.64	64.95
Al_2O_3	14.27	14.97	16.13	15.78	15.25	15.09	16.27	15.44
Fe_2O_3	.51	.79	2.22	1.58	1.69	1.37	2.42	2.02
FeO	.26	.34	.44	.85	1.13	1.17	1.58	1.60
MgO	.24	.66	.72	1.43	1.75	2.39	1.27	2.65
CaO	1.10	2.10	1.36	2.38	2.17	2.38	2.65	3.07
Na_2O	3.43	3.38	4.37	4.11	4.09	3.96	4.39	4.25
K_2O	4.90	4.40	4.89	4.87	5.10	4.91	4.98	3.87
$H_2O+110°$ ..	.73	.92	.58	.70	.51	.60	.27	.85
$H_2O-110°$ ..	.68	1.09	.20	.32	.56	.39	.09	.26
TiO_2	.08	.28	.32	.32	.20	.27	.51	.39
Cr_2O_3	....	....	....	....	....	....	....	....
MnO	.06	Trace.	Trace.	Trace.	.05	.06	Trace.	Trace.
SrO	Trace.	.06	.09	.09	.03	.07	.08	.10
BaO	Trace.	.14	.27	.24	.33	.30	.18	.35
Li_2O	Trace.	Trace.	Trace.	Trace.	Trace (?)	Trace.	....	....
P_2O_5	.03	.17	.18	.21	.21	.15	.37	.25
CO_2	.77	.88	....	....	....	.45	.37	....
SO_3	....	Trace.	Trace.	Trace.	....	....	Trace.	.02
Cl	....	Trace.	Trace.	Trace.	....	....	.05	.04
Fl	....	....	....	....	....	....	....	....
Total ...	100.18	99.86	100.37	100.32	100.11	99.85	100.12	100.11

I. Rhyolite-porphyry, intrusive sheet Yogo-Baldy Ridge.
II. Granite-porphyry, Wolf Butte.
III. Granite-porphyry, top of Barker Mountain laccolith.
IV. Granite-porphyry, north end of Thunder Mountain laccolith.
V. Granite-porphyry, top of Big Baldy Mountain laccolith.
VI. Granite-syenite-aplite, dike head of Sheep Creek.
VII. Syenite, Wright and Edwards mine, Hughesville, near Barker.
VIII. Syenite-diorite-porphyry, talus, head of Bear Park.

of the Little Belt Mountain, Montana.

IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.	XVII.
62.18	61.65	62.58	54.42	52.26	48.98	48.35	48.39	55.13
15.77	15.07	16.42	14.28	13.96	12.29	13.27	11.64	20.27
1.83	2.03	2.46	3.32	2.76	2.88	4.38	4.09	1.52
2.44	2.25	1.96	4.13	4.45	5.77	3.23	3.57	4.29
3.55	3.67	1.84	6.12	8.21	9.19	8.36	12.55	1.80
4.13	4.61	2.47	7.72	7.06	9.65	9.94	7.64	7.05
3.92	4.35	4.57	3.44	2.80	2.22	3.35	4.14	4.31
3.91	4.50	3.91	4.22	3.87	4.96	3.01	3.24	2.84
.70	.41	1.40	.38	1.34	.56	2.89	2.56	.95
.30	.26	.38	.22	1.53	.26	.90	.28	.14
.55	.56	.40	.80	.58	1.44	.52	.73	.74
....	Trace.	....	Trace.	Trace.	Trace.	Trace.	.07	....
Trace.	.09	.08	.10	.14	.08	.19	Trace.	.13
.16	.10	.10	.13	.05	.08	.09	.15	.06
.43	.27	.41	.32	.23	.43	.54	.32	.11
Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.	Trace.
.32	.33	.33	.59	.52	.98	.40	.45	.40
....	....	.77	....	.49	....	.30	....	.26
Trace.	....	....	....	....	....	....	.08	....
.04	....	....	....	....	....	....	Trace.	....
....	....	....	....	....	.22	.25	....	....
100.23	100.15	100.08	100.19	100.25	99.99	100.01	99.90	100.00

IX. Diorite-porphyry, Steamboat Mountain laccolith.
X. Syenite (banatite), Yogo Peak, east end.
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XIII. Minette, intrusive sheet, head of Sheep Creek.
XIV. Shonkinite, Yogo Peak, west end.
XV. Analcite-basalt dike, Big Baldy Mountain.
XVI. Analcite-basalt dike, Bandbox Mountain.
XVII. Diorite, Carpenter Creek, near Neihart.

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